Appendix B

Bel Marin Keys Hydrologic and Hydraulic Modeling and Supporting Information

Memorandum

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Date:	14 October 2002	**Project:**	50283
To:	Rich Walter		
Company/Agency:	Jones & Stokes		
From:	Brad Hall		
Subject:	Hydrologic and Hydraulic Modeling Assessment of Existing and Project Alternatives at Bel Marin Keys V		

This memorandum is issued to clarify citations presented in the 18 April 2002 memorandum. The analyses, results, and conclusions of this memorandum were not modified from the 18 April 2002 memorandum.

Overview

This document presents Northwest Hydraulic Consultants (**nhc**) investigation of the hydraulic impact of the proposed Bel Marin Keys tidal marsh restoration project. This study quantitatively assesses the relative change of the proposed project on Pacheco Pond stages and Novato Creek stages from the Pacheco Pond outlet to the creek mouth.

The proposed tidal marsh restoration at Bel Marin Keys will affect the hydrology of several elements within the lower Novato Creek basin. Proposed modifications to Pacheco Pond and the proposed diversion of flow away from Novato Creek considered in the design alternatives will present the most substantial effects. The proposed modifications to Pacheco Pond consist of either expanding the existing pond, or creating a seasonal marsh adjacent to the pond. In addition, the diversion of water currently flowing into Novato Creek from Pacheco Pond, to the proposed tidal marsh will greatly affect existing conditions on the Bel Marin Keys tidal wetlands restoration site. These flows will provide fresh water for the proposed freshwater marsh portion of the project.

To assess the impacts of the proposed tidal wetland restoration on the hydrology of the existing site a review of hydrologic studies of the Novato Creek and Pacheco Pond watersheds was completed. Existing and proposed site conditions that affect the drainage and flooding characteristics were identified. Representative flood hydrographs and tidal stage characteristics were determined and used for computing flood stage and discharge conditions in the study area. To quantify the changes in flood stage and discharge magnitude resulting from coincident terrestrial and tidal flood conditions, a one-dimensional, unsteady flow model of the Novato Creek and Pacheco Pond system was developed. Described below are some features of this modeling effort, including a description of the basin, the proposed alternatives, the model itself, and the model results.

Basin Description

The components of the Pacheco Pond watershed consist of two small streams, Pacheco Creek and Arroyo San Jose, which drain into a constructed detention reservoir, Pacheco Pond. Pacheco Pond currently discharges into Novato Creek and finally, San Pablo Bay (Figure 1). Historically, Pacheco Creek and Arroyo San Jose discharged into the tidal marsh to the south of the Bel Marin Keys development. The specific features of the watershed are described below.

- *Pacheco Creek*

Pacheco creek drains a 1.9 square mile watershed. From the headwaters 3 miles to the west, the stream crosses several roads, including Highway 101, through a series of culverts. Flooding is known to occur in the lower reaches of Pacheco Creek, prior to entering Pacheco Pond, for flood events with magnitudes less than the 10-year event (1).

However, because this study focused on the area downstream of Pacheco Pond, the flooding of the creek upstream of the pond was not analyzed in the modeling study. Flows of Pacheco Creek into the pond were modeled as an inflow hydrograph entering the pond, as will be described below. Additional survey of channel cross sections and physical characteristics of the local storm drainage system would be required to quantify flooding conditions upstream of Pacheco Pond and within the Ignacio Business Park.

- *Arroyo San Jose*

The Arroyo San Jose watershed drains an area of approximately 5.4 square miles. Arroyo San Jose accounts for approximately three-quarters of the inflow to Pacheco Pond (2). Previous hydrologic studies of the basin indicate that the Arroyo San Jose remains within its banks for flood events up to the 100-year flood. However, accompanied with high tides in Novato Creek and the associated constriction of flow release from Pacheco Pond, the 100-year event can cause minor flooding of residential and business areas near the confluence with Pacheco Pond (1).

- *Pacheco Pond*

Pacheco Pond covers an area of approximately 120 acres. The estimated flood storage volume between elevations 0.0 and 7.0-ft, NGVD 29, is approximately 866 acre-ft. The storage volume of the reservoir was estimated from existing topographic surveys, aerial photos, and previous engineering studies (3, 4). A stage-volume relation for Pacheco Pond was determined and utilized to compute the pond storage and resultant water surface elevation during storm events.

Pacheco Pond discharges into Novato Creek via a leveed channel controlled by six 4-ft by 4-ft flap gated culverts. The invert elevation of the culvert structure was independently surveyed by **nhc** and the Marin County Flood Control District to have an invert elevation of –0.86-ft, NGVD 29. It appears that the invert of the culvert was not accurately surveyed in earlier studies of Pacheco Pond hydrology, and was reported to have an invert elevation of –1.8-ft, NGVD 29 (2). The effect of the flap gate was modeled by only allowing flow in the positive direction (toward Novato Creek) through the box culvert. Minor leakage and backflow through the flap gates was not modeled in this analysis.

During high flow events the water level in Pacheco Pond can exceed adjacent levee elevations. The lowest point exists north of the pond, adjacent to the Leveroni property, where the measured low point of the levee is 5.6-ft, NGVD 29 (2). These low points were considered in the model by including lateral weirs to direct flow to adjacent storage areas when stages in the pond exceeded 5.6-ft. Top of levee surveys also indicate that a significant extent of this levee is at an elevation of approximately 6.7-ft, NGVD 29. Additional lateral overflow weirs were specified at this higher top of levee elevation in the hydraulic model.

- *Novato Creek*

Novato creek is the main drainage course in the region with an approximate total watershed area of 44 square miles (5). However, breakout flows due to flow constrictions at the railroad bridges downstream of Highway 101, and adjacent to Highway 37, reduce the overall peak flood discharge (6). An infinite variation in the timing of peak discharges between Novato Creek and Pacheco Pond hydrographs is possible; however, the Novato Creek peak would be expected to lag the Pacheco Pond peak due to the larger watershed area of Novato Creek. Water surface conditions within Pacheco Pond and within Novato Creek were evaluated for lag times between peak flows of zero, six, and 12 hours.

Cross sections of Novato Creek were developed by **nhc** from existing LiDAR (3) and bathymetric surveys (7). The cross sections depict the subtidal channel of the creek, adjacent tidal marsh surface, and existing levee structures that currently constrain the Novato Creek floodplain. Top of levee surveys completed in 1996, indicate that the levee crest between Novato Creek and the Bel Marin Keys V site dips to an elevation of approximately 5.6-ft, NGVD 29, at a point approximately 1000 feet downstream from the Bel Marin Keys South Lagoon navigation lock. Overtopping of this levee was observed by Bel Marin Keys residents in the February 1998 flood event. The location of this overtopping was incorporated in the hydraulic model by specifying an overtopping weir with a crest elevation of 5.6-ft, in the model geometry at this location.

- *San Pablo BayTides*

Tides in San Pablo Bay follow a mixed semidiurnal cycle, with two high and two low tides, of differing heights, occurring in a single day. Due to geographic and hydrodynamic complexities, mean tide levels vary throughout the San Francisco/San Pablo Bay system. Tide cycles in San Pablo Bay are seen to lag those at the Golden Gate by as much as 75 minutes (2). Peak tide water surface elevations in the vicinity of Novato Creek are reported as 6.0-ft, NGVD 29 for the 10-year tide and 6.5-ft, NGVD 29 for the 100-year tide (8). FEMA maps tidal water surface elevations to the nearest whole-foot (9). Therefore, the Base Flood Elevation resulting from tidal flooding in the City of Novato is 7 feet (10).

Storm events lead to higher tidal stages than those predicted by gravitational forces for a variety of reasons. First, low barometric pressures associated with significant storm frontal passage leads to a regional rise in tidal stage as the oceans surface level increases in response to the reduction in overlying atmospheric pressure. Second, wind stresses may lead to a storm surge setup, further increasing peak tidal stage. Third, increases in large scale regional runoff from the Sacramento and San Joaquin watersheds, as well as contributions from San Francisco Bay watersheds, limit the low tidal excursion of normal tidal cycles. San Pablo Bay, in essence, is filled with regional runoff (11).

The tide measurements taken at the mouth of the Petaluma River were utilized to develop time series of tidal stage hydrographs at the mouth of Novato Creek. These data, completed as part of the San Francisco Airport runway expansion dredge material disposal studies, consist of tidal stage measurements recorded at 10-minute increments for the duration of approximately one month (14 June - 17 July 2000) (3). Earlier studies of Novato Creek indicate negligible differences between Novato Creek and Petaluma River tidal stage characteristics (2). To conservatively estimate tidal conditions during flood events, these tide stage data were modified in two ways to reflect extreme tidal conditions that occur during significant flooding events. The first modification was to increase the observed peak tidal stage by one foot to reflect extreme high tides due to low atmospheric pressure and wind setup in the region. This is equivalent to coincident tidal stage boundary conditions frequently used by the Corps of Engineers and the FEMA for flood control design or flood hazard mapping studies on tidally influenced streams and rivers (12). The resulting peak tide is 5.75 feet, 0.25 feet lower than the 10-year peak tide of 6 feet. The second modification was to truncate the low tide elevation at the mean tide level to represent limits on low tide excursion due to extreme regional, basin-wide runoff conditions.

Alternative Descriptions

The descriptions of Alternatives 1, 2, and 3, given below consist of that information that is relevant to the hydrologic modeling effort. That is, only the elements that affect the hydrology and hydraulics of the site are considered. For all project alternatives, Pacheco Pond flows will be routed to Novato Creek during storm events. In the following analyses, Pacheco Pond flows were routed to the restored tidal marsh for all project alternatives. The key hydrologic characteristics of the three alternatives are described below:

Alternative 1

- Pacheco Pond expanded to a capacity of approximately 1241 acre-ft (above 0-ft, NGVD 29)
- flow diverted to proposed tidal marsh from Pacheco Pond through a flap gated culvert structure identical to the existing one at Novato Creek

Alternative 2

- seasonal wetland constructed adjacent to existing Pacheco Pond with a storage volume of approximately 1155 acre-ft (above 0-ft, NGVD 29)
- existing Pacheco Pond and seasonal wetland connected with a 100-ft wide weir, with a crest elevation of 2-ft, NVGD 29
- flow from the seasonal wetland is released to the proposed tidal marsh through a flap gated culvert structure identical to the existing one at Novato Creek

Alternative 3

- for the purposes of this analysis, identical to Alternative 1

UNET Model Description

To evaluate the hydraulics of the existing study basin, as well as the proposed project conditions, the hydraulic modeling program UNET was employed. UNET was developed by the U.S. Army Corps of Engineers, and provides a modeling framework for computing solutions to one-dimensional, unsteady flow problems in complex networks. The choice of using such a model was deemed necessary here due to the dynamic conditions caused by both the fluctuating tide levels in San Pablo Bay, and the rapid changes in water surface elevation expected within Pacheco Pond.

The UNET model requires hydraulic boundary conditions for both the upstream and downstream ends of the study site. For this study, the downstream boundary conditions consisted of the modified, tidal time series measured at the mouth of the Petaluma River as described above. The tidal time series data are shown in Figure 2.

The upstream boundary conditions consisted of inflow storm hydrographs. The storm hydrographs for Pacheco Creek at Pacheco Pond, Arroyo San Jose at Pacheco Pond, and Novato Creek near Highway 37 were obtained from previous studies (2, 5, 6). The hydrologic conditions considered in the analysis consisted of two scenarios. These scenarios, referred to here as A and B, are meant to loosely represent the 10-year and 100-year storm events, respectively. However, a detailed assessment of present and future watershed conditions, coincident storm peak flow analysis, and hydrologic routing characteristics that would more accurately define the expected characteristics of storm hydrographs was beyond the scope of this study. The flow hydrographs for Arroyo San Jose, Pacheco Creek, and Novato Creek for both scenarios A and B are shown in Figures 3, 4, and 5.

Theoretically, there are infinite combinations of phasing between the peak tide and the peak discharge hydrographs. To simplify the analysis, Pacheco Creek and Arroyo San Jose hydrographs were phased to be coincident with the higher high water tidal stage for all model runs. However, the phasing of the Novato Creek hydrograph was varied to investigate the effect of lag times on system. Due to the larger watershed dimensions, the peak discharge from Novato Creek would be expected to lag the Pacheco Pond peak discharges. Novato Creek hydrographs specified at three different lag times relative to the peak hydrograph from the Pacheco Pond watershed: 0-hour lag time (i.e. coincident with the higher high water tide stage and other hydrographs), 6-hour lag time (i.e. 6 hours behind other hydrographs), and 12-hour lag time. The adjustment of phasing was only relevant to the model runs that evaluated the existing conditions, as Pacheco Pond flows are routed away from Novato Creek for all project condition scenarios.

The general modeling strategy was to isolate elements within the drainage system in order to assess their relative effect on peak flows and water surface elevations. A key caveat of this analysis is that the primary consideration should be in comparing *relative* differences between computed peak discharges and water surface elevations. Detailed and consistent surveys of the physical characteristics of Pacheco Pond and Novato Creek are necessary to identify accurate, water surface elevations. These surveys were beyond the scope of this conceptual planning effort. However, *relative* differences in peak water surface elevations and flowrates between the alternative conditions assessed in this analysis are fairly insensitive (less than 0.25 feet) to the small changes in absolute geometric conditions (e.g. plus or minus 1-foot of vertical difference in invert elevations). Thus, the relative changes between existing and project alternative conditions can be used to assess project performance and impacts.

Four cases were considered. The first consisted of modeling the existing Pacheco Pond-Novato Creek system. The second case considered only Novato Creek, without contributing flows from Pacheco Pond, and the third and fourth cases considered only the isolated Pacheco Pond. These third and fourth cases were used to evaluate the effects and differences between Alternatives 1 & 3, and 2, on pond hydraulics. The primary assumption in the third and fourth cases is that the entire flow into Pacheco Pond will be rerouted to the proposed tidal marsh. Table 1 outlines the modeling conditions for each case.

Table 1. UNET Model Conditions

Case	Model Conditions
Existing Novato Creek and Pacheco Pond Network - Evaluates the interaction between Pacheco Pond and Novato Creek for existing conditions	**Boundary Conditions** • Arroyo San Jose: Scenario A and B Hydrographs • Pacheco Creek: Scenario A and B Hydrographs • Novato Creek: Scenario A and B Hydrographs; 0, 6, 12 hour lag • San Pablo Bay: Truncated/amplified tide series **Model Elements** • Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow to Novato Ck • 100-ft wide lateral weir at 5.6-ft, NGVD 29 for pond overflow to Leveroni Property • 1000-ft wide lateral weir at 6.7-ft, NGVD 29 for pond overflow • 300-ft wide lateral weir at 5.6-ft, NGVD 29 for Novato Ck overflow to BMKV wetlands restoration site downstream of BMK residential development.
Project Conditions on Novato Creek- Evaluates only Novato Creek while considering influence of added restored tidal prism downstream of BMK residential development. The connection with Pacheco Pond is removed from the model.	**Boundary Conditions** • Novato Creek: Scenario A and B Hydrographs; 12 hour lag • San Pablo Bay: Truncated/amplified tide series **Model Elements** • right bank levee removed downstream of BMK residential development • right bank floodplain expanded laterally by 1000-ft downstream of BMK residential development to reflect opportunity for overflow into restored tidal marsh • 450-acre tidal marsh modeled as storage area with hydraulic connection through new breach channel to lower Novato Creek.
Pacheco Pond Configuration for Alternative 1 & 3 - Evaluates an expanded Pacheco Pond with a flap gate outlet to the tidal marsh	**Boundary Conditions** • Arroyo San Jose: Scenario A and B Hydrographs • Pacheco Creek: Scenario A and B Hydrographs • San Pablo Bay: Truncated/amplified tide series **Model Elements** • Pacheco Pond expanded • Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow to tidal marsh
Pacheco Pond Configuration for Alternative 2 - Evaluates Pacheco Pond with an adjacent seasonal marsh storage area, flow controlled by weir and flap gate structure	**Boundary Conditions** • Arroyo San Jose: Scenario A and B Hydrographs • Pacheco Creek: Scenario A and B Hydrographs • San Pablo Bay: Truncated/amplified tide series **Model Elements** • Additional 650-acre storage area attached to Pacheco Pond to simulate constructed seasonal wetland • 100-ft wide inline weir to control flow from pond to seasonal marsh • Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow to tidal marsh

Model Results

The UNET model results of primary interest are the effects of the proposed tidal restoration on the stage within Pacheco Pond and Novato Creek. With respect to the former, comparison between the stage hydrographs within the existing pond (Figs. 6 and 7) and those of Alternatives 1 & 3, and 2 (Figs. 8 and 9), show that the proposed changes will substantially reduce peak water surface elevations within Pacheco Pond (Table 2). This reduction in Pacheco Pond elevations will have a positive benefit on Ignacio Business Park drainage conditions that are presently aggravated by high stages within Pacheco Pond. The magnitude and extent of this improvement to local storm drainage conditions, however, was not quantified in this analysis.

Table 2. Peak Water Surface Elevations in Pacheco Pond (ft, NGVD 29)

Case	Scenario A	Scenario B
Existing	6.4	7.6
Alternative 1 & 3	4.5	7.2
Alternative 2	4.6	6.3

Also of interest are the effects of the proposed project on stages within Novato Creek. Under the project alternatives being considered for the Bel Marin Keys tidal wetland restoration, all flow from Pacheco Pond will be diverted away from Novato Creek and routed through new drainage structures into the proposed tidal marsh. To examine the effect of this diversion, stage hydrographs at select locations along Novato Creek are presented in Figures 10 and 11, for scenarios A and B, respectively. The locations chosen include the upstream limit of the model at Highway 37 bridge (CS 10), at the existing confluence of Pacheco Pond with Novato Creek (CS 8), and just downstream of the lower Bel Marin Keys navigational lock (CS 4).

The stage hydrographs shown in Figures 10 and 11, suggest that peak water surface elevations within Novato Creek are controlled primarily by tidal fluctuations. That is, the effects of diverting Pacheco Pond flow, in addition to the added tidal prism created by the constructed tidal marsh, do not substantially change the peak water surface elevations between existing and project conditions. The changes that do occur are a negligible drop (less than 0.1 foot) in peak stage when Pacheco Pond flow is diverted.

References:

1. Jones & Stokes Associates Inc., 1998 (December), "Hamilton Army Airfield Wetland Restoration, Final EIR/EIS" California State Coastal Conservancy, and U.S.A.C.E, S.F.

2. Philip Williams & Associates Ltd., 1998 (October), "Appendix E: Hamilton Base Realignment & Closure, Wetland Conversion Alternative: Airfield Panhandle Flood Assessment", Prepared for IT Corp.

3. San Francisco International Airport's Airfield Development Engineering Consultant (ADEC). 2000. (1) Text file, EXCEL spreadsheet with bathymetry and tide data; (2) digital orthometric photography; (3) LiDAR topography, vertical

datum NGVD 1929, horizontal datum NAD 1983. Provided by Moffit Nichol Engineers.

4. Gonzalez and Oberkamper Civil Engineers, Inc., 1975. “Appendix IV Drainage Analysis Ignacio Industrial Park Marin County, California”. Prepared for Madrone Associates Environmental Consultants. “Final Environmental Impact Report Ignacio Industrial Park, Unit 3”.

5. U.S. Army Corps of Engineers, San Francisco District, 1987, "Hydrologic Engineering Report, Novato Creek and Adjacent Streams", City of Novato, Marin County, California.

6. CSW/Stuber-Stroeh Engineering Group Inc., 1996 (January), "Bel Marin Keys V Master Storm Water Management Plan", Prepared for the Presidio Group.

7. Towill, Inc. 1996. “Hydrographic Survey of Novato Creek performed on July 31 and August 1 for the Bel Marin Keys Community Services District.” San Francisco, CA.

8. San Francisco District, Corps of Engineers, 1984. “San Francisco Bay, Tidal Stage vs. Frequency Study,” San Francisco, CA.

9. Federal Emergency Management Agency (FEMA), 2002. “Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix D: Guidance for Coastal Flooding Analyses and Mapping”, www.fema.gov/mit/tsd/dl_cgs.htm.

10. Federal Emergency Management Agency (FEMA), 2002. “City of Novato, California, Flood Insurance Rate Map Community-Panel Number 060178 0005 B”, Map Revision Date April 3, 1984.

11. Charles D. Anderson, Katherine M. Oven, Christy Chung, 2000. “Surf’s Up – or Tide Cycles During Storm Events.” Spring 2000 Floodplain Managers Association Conference, San Diego, CA.

12. U.S. Army Corps of Engineers, Sacramento District. 1993. “Coyote and Berryessa Creeks, California Final General Design Memorandum”.

Figure 1
Hydrologic Setting at the Project Site

N

1000 0 1000 2000 3000

Scale = 1:20,000
(1 inch = 1,666 feet)

Jones & Stokes nhc

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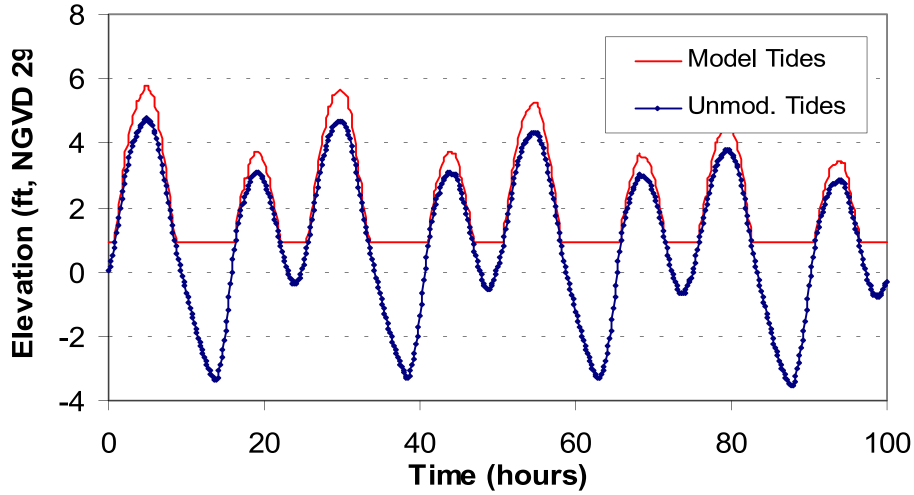

Figure 2. Unmodified tide series, and tide series used in UNET model

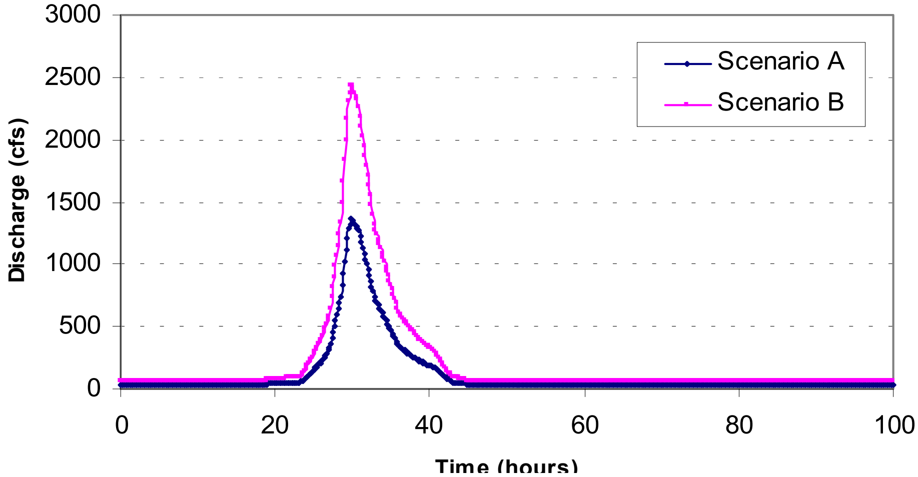

Figure 3. Arroyo San Jose Input Hydrographs

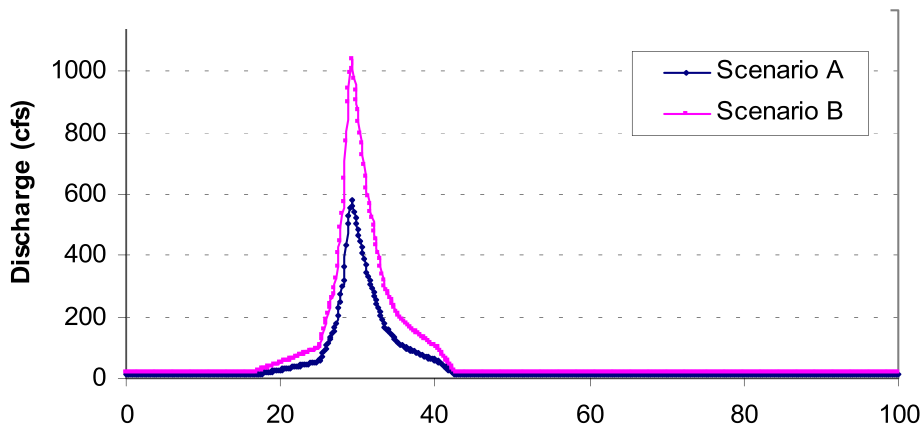

Figure 4. Pacheco Creek Input Hydrographs

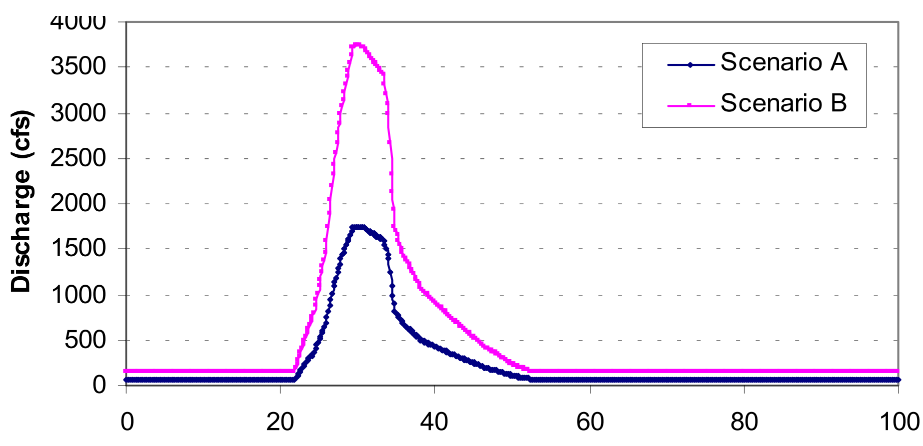

Figure 5. Novato Creek Input Hydrographs (0-hour lag)

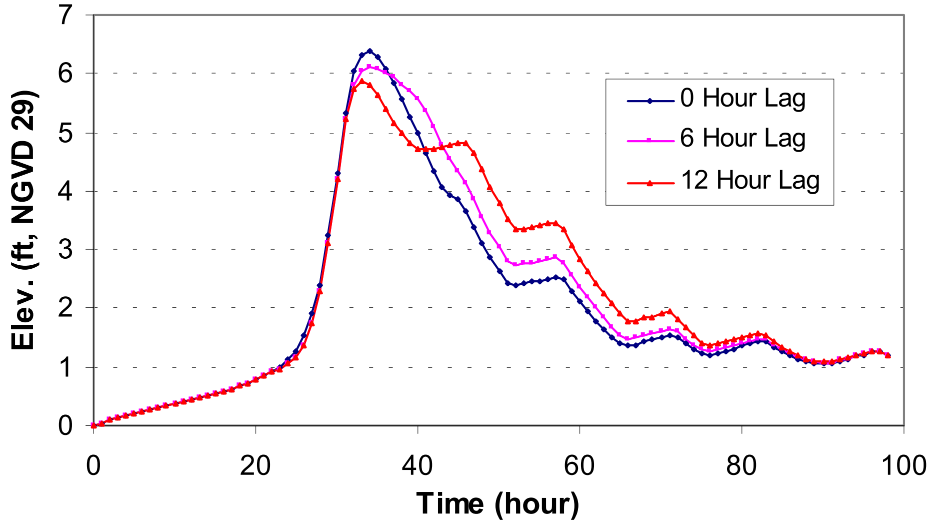

Figure 6. Pacheco Pond water surface elevations, existing conditions, Scenario A

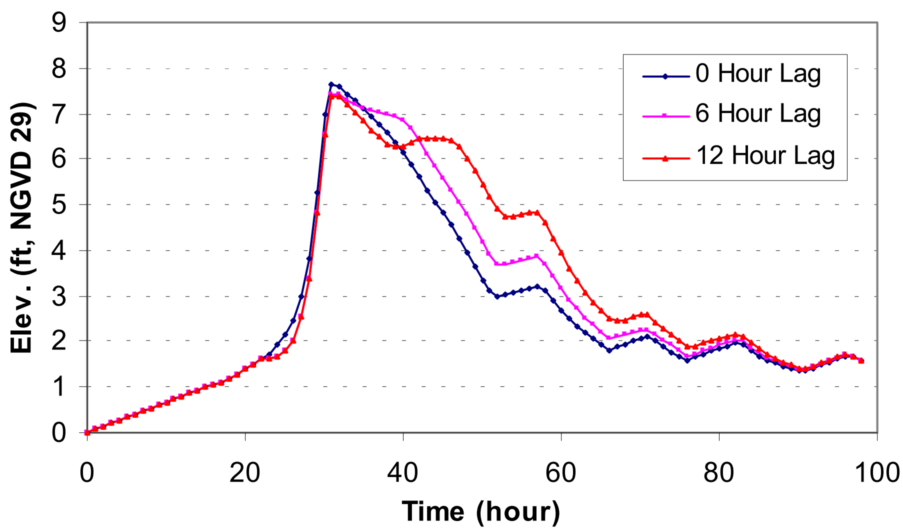

Figure 7. Pacheco Pond water surface elevations, existing conditions, Scenario B

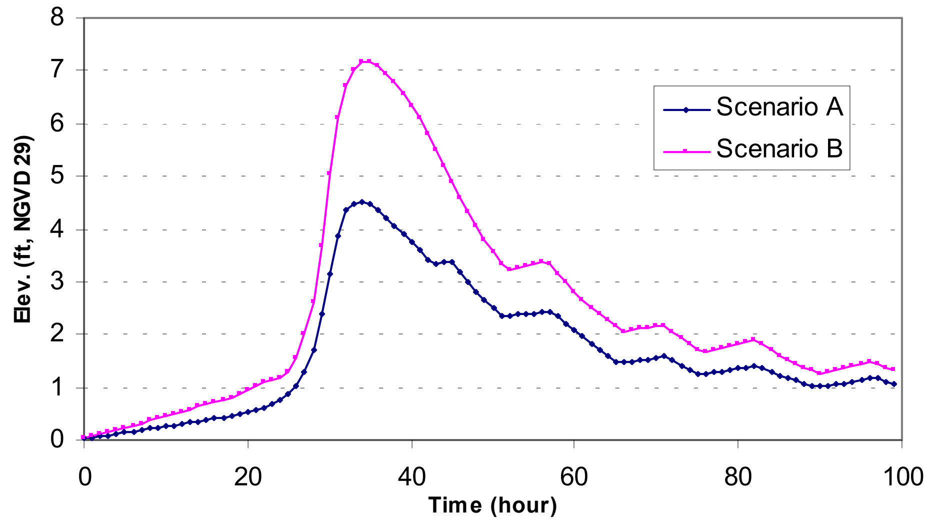

Figure 8. Pacheco Pond water surface elevations, Alternatives 1 & 3

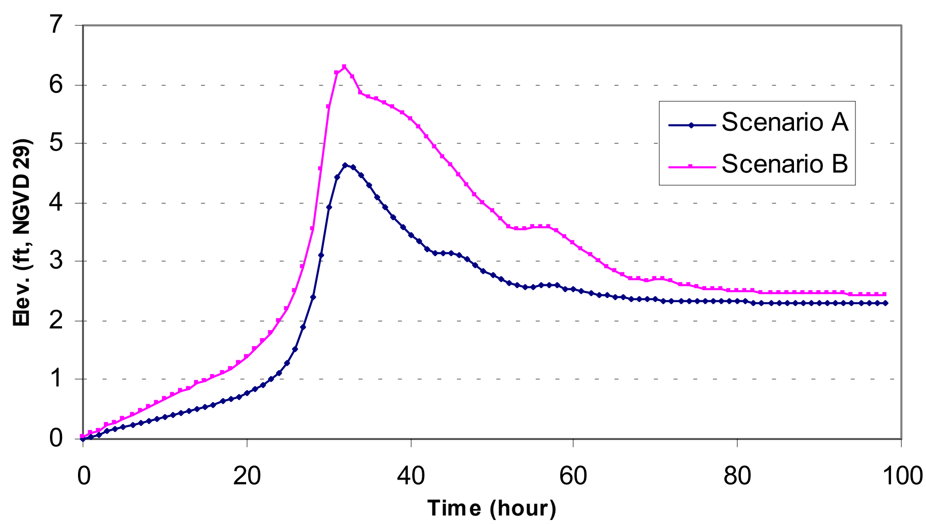

Figure 9. Pacheco Pond water surface elevations, Alternative 2

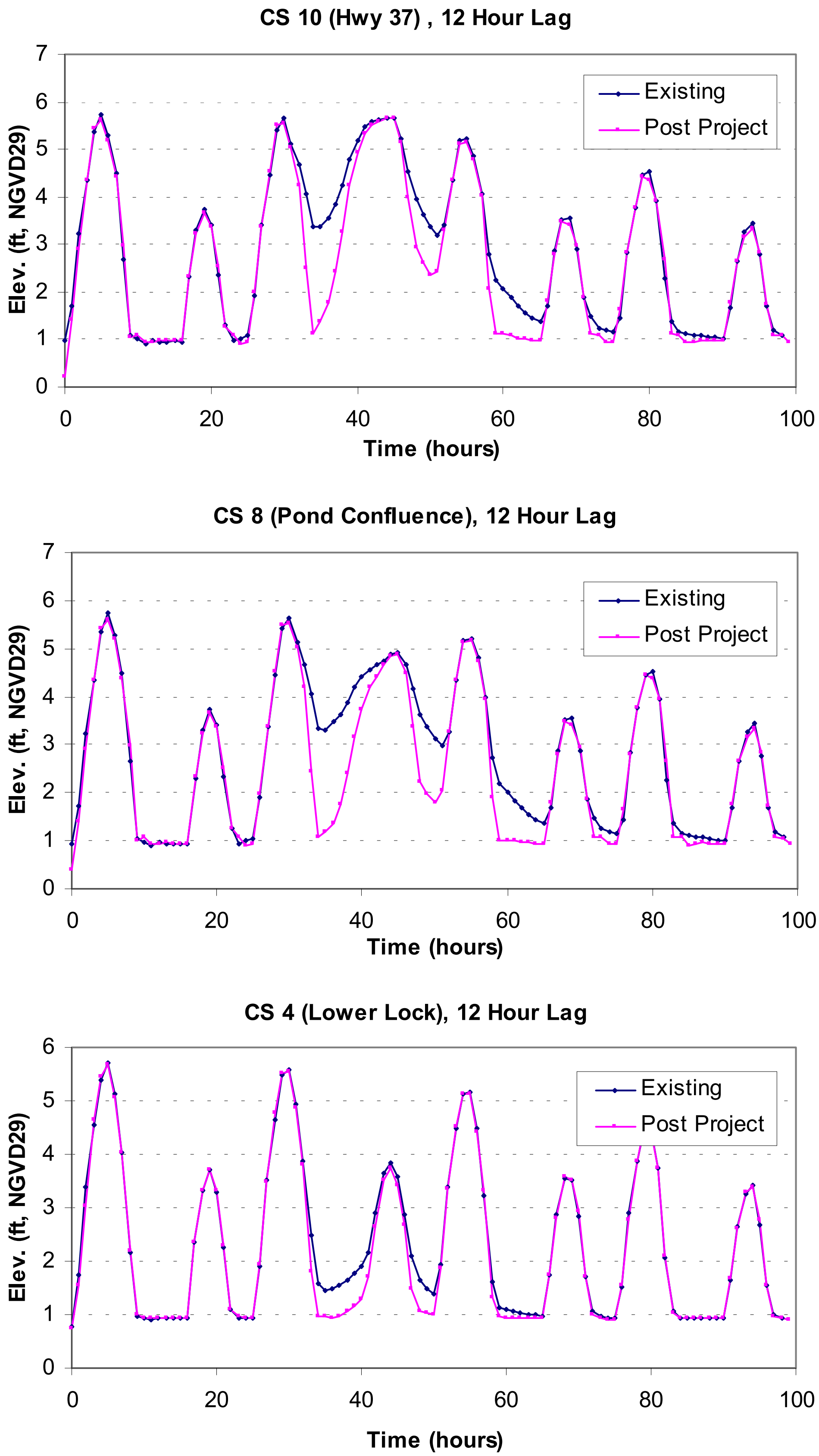

Figure 10. Stage hydrographs at select locations along Novato Creek, Scenario A

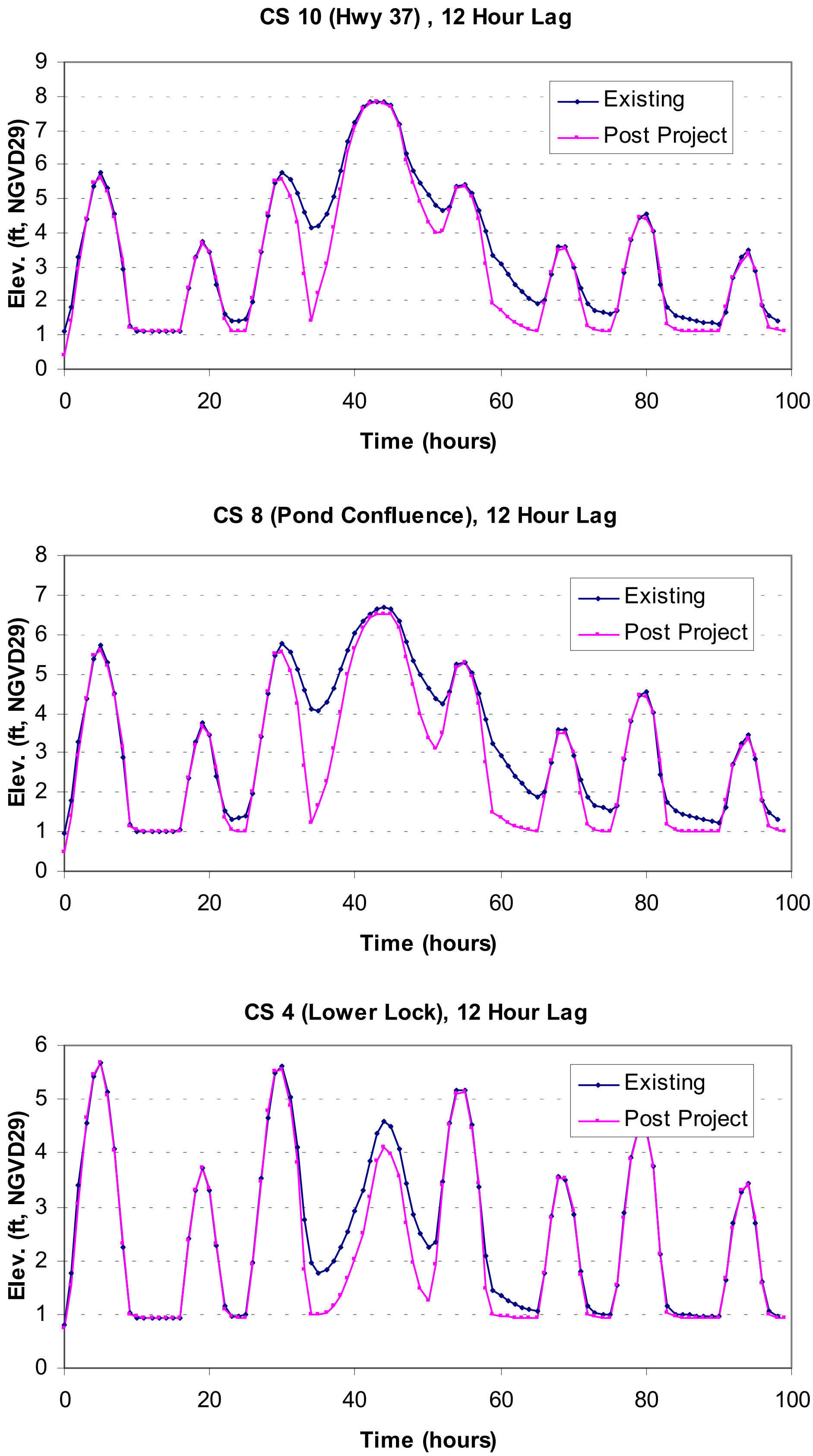

Figure 11. Stage hydrographs at select locations along Novato Creek, Scenario B

Bel Marin Keys Unit V Expansion of the Hamilton Wetland Restoration Project

Hydraulic Routing Analysis

Purpose
This document presents a hydraulic impact investigation performed by Northwest Hydraulic Consultants (**nhc**) of the proposed Bel Marin Keys tidal marsh restoration project on Pacheco Pond and Novato Creek. The purpose of the study was to quantify the relative hydraulic effects of the proposed project on Pacheco Pond and on Novato Creek from the Pacheco Pond outlet to San Pablo Bay.

This document describes supplementary hydrologic and hydraulic analyses initially presented in the technical memorandum entitled "Hydrologic and Hydraulic Modeling Assessment of Existing and Project Alternatives at Bel Marin Keys," dated April 18, 2002 (**nhc**, 2002a). Supplementary information presented in the following sections of this report includes a refinement of the geometric conditions for Alternative 2, as well as an assessment of additional scenarios for evaluating the effects of Pacheco Pond on existing and project alternative conditions on Novato Creek flood dynamics. Computed time histories of channel velocity, flow rate, and water surface stage for several hydrologic scenarios are also presented in this report.

Background
Over the last two centuries, hydrologic conditions in the Novato Creek watershed below Highway 37 have varied dramatically due to changes in land use practices and engineered modifications to the land surface. These modifications include the construction of flood protection levees, the development of Pacheco Pond as a flood detention system, and the rerouting of drainage channels and installation of flap gates on Simmons Slough and Pacheco Pond. This has decreased the tidal prism of lower Novato Creek significantly, and has resulted in accretion of the channel. The reduction in channel size due to accretion has decreased the flood capacity of the system and has proved undesirable for navigation. The creek is constantly evolving toward a smaller width and depth consistent with the reduced tidal prism. Actions to counter the effects of channel accretion include the periodic surveying and raising of levees along the north side of Novato Creek from Highway 37 to the mouth and dredging of Novato Creek downstream of its confluence with Pacheco Pond.

Hydraulic Setting
Novato Creek is the principal drainage in the vicinity of the project site and has an approximate total watershed area of 44 square miles. Two smaller drainages, Arroyo San Jose (drainage area of 5.4 square miles) and Pacheco Creek (drainage area of 1.9 square miles) discharge into Pacheco Pond. The pond ultimately drains into Novato Creek by means of six 4-foot by 4-foot flap gates. The flap gates open when the stage in Pacheco Pond exceeds the stage in Novato Creek and the invert of the flap-gate culvert, which is approximately -0.86 feet NGVD 29. In addition, Simmons Slough drains lowlands to the north of Novato Creek and discharges into Novato Creek through a flap gate culvert downstream of the Pacheco Pond culvert.

The Bel Marin Keys Community Service District (CSD) operates two locks that provide recreational vessel access to the North and South Lagoons of the community. The North Lock facility includes three tainter gates used for lagoon flushing purposes. Managed releases from the lagoons are conducted by the CSD to promote channel scour in Novato Creek to improve navigability of the tidally influenced portion of Novato Creek. A location map showing the project site and adjacent areas is provided in Figure 1.

Downstream of Highway 101, the geometry of Novato Creek is characteristic of tidally influenced channels throughout San Francisco Bay, and is composed of a consolidated bay mud main channel with tidal salt marsh benches. The slope of the lower channel is relatively mild, with a general longitudinal slope of

0.002 ft/ft between Highway 101 and Diablo Avenue to approximately 0.0001 ft/ft near the mouth. These slopes result in subcritical flows throughout the lower reach, even during storm events. However, critical and supercritical flows may occur in discrete locations during low tide conditions.

Novato Creek transitions from channel-control to tidal-control within this reach, as the slope of the creek reduces and the creek elevations come within San Pablo Bay tidal range. Tidal effects from San Pablo Bay become apparent and influence the stage of the creek, as the creek stage rises and falls with the tidal stage in San Pablo Bay. The location of the transition point from channel- to tidal-control varies with the magnitude of terrestrial inflows and tide stage characteristics.

Channel conveyance, and thus discharge capacity, in lower Novato Creek is directly related to the tide level. Since both the tide stage and inflows to Novato Creek vary with time, the channel conveyance also varies in time. Furthermore, since conveyance is a function of both terrestrial inflow and tide, peak stages in lower Novato Creek do not necessarily occur during the peak flow. The time-dependant effects of the changing inflows and tide (referred to as hydraulic boundary conditions) necessitate the application of a dynamic model to properly simulate the physical processes of tidally influenced, unsteady creek flow.

Although tidally influenced systems are unsteady by nature, steady-state hydraulic models, or models in which the boundary conditions do not vary with time, can be used to conservatively estimate water surface profiles and discharge in tidal channels. Steady-state models are simpler to operate and were more commonly applied prior to the advent of modern personal computers. Using HEC-2, a steady-state model developed by the Corps of Engineers, FEMA calculated a maximum channel conveyance capacity downstream of Highway 37 of 2,500 cfs (FEMA, 1989). It is worth noting that this is significantly less than the effective 10-year peak discharge of 3,420 cfs discharge published in the City of Novato FIS (FEMA, 1989).

The 1984 City of Novato Flood Insurance Rate Map published by FEMA indicates a nearly flat water surface coincident with the peak 100-year tidal stage in the lower reach of Novato Creek, revealing the dominance of tidal flooding over terrestrial flooding in Novato Creek downstream of Highway 37 for the one percent annual exceedance probability (100-year recurrence interval) flood. These predicted tide stages are based on tide stage frequency analyses conducted by the Corps. The 1989 City of Novato FIS rounds the Corps tidal flood stage of 6.5 feet NGVD 1929 to 7 feet NGVD 29 as per FEMA mapping guidelines (FEMA 2002).

Tides in San Pablo Bay follow a mixed semidiurnal cycle, with two high and two low tides, of differing heights, occurring in a single day. Due to geographic and hydrodynamic complexities, mean tide levels vary throughout the San Francisco Bay. Tide cycles in San Pablo Bay lag those at the Golden Gate Bridge by as much as 75 minutes. Peak tide levels in the vicinity of Novato Creek are 6.0 ft NGVD 29 for the 10-year tide and 6.5 ft NGVD 29 for the 100-year tide (San Francisco District, 1984).

Storm events may lead to higher tidal stages than those predicted by gravitational forces for a variety of reasons. First, low barometric pressures associated with significant storms can cause an increase in tidal stage, as the ocean’s surface level increases in response to the barometric low. Second, strong wind shear may push water towards land, leading to the phenomenon of a storm surge. Third, increases in large-scale regional runoff from the Sacramento and San Joaquin watersheds, as well as contributions from San Francisco Bay watersheds, can limit the low tidal excursion of normal tidal cycles. San Pablo Bay, for instance, is filled mainly by regional runoff and runoff from the Sacramento and San Joaquin River systems (Anderson et al., 2000).

Model Selection

The hydraulic modeling program UNET was utilized to evaluate the existing hydraulic conditions of lower Novato Creek, as well as evaluate the hydraulic conditions for the proposed project conditions. UNET is a one-dimensional model, developed by the U.S. Army Corps of Engineers, and provides a modeling framework for computing solutions to unsteady flow problems in channel networks. UNET also provides routines for evaluating levee overflow to floodplain storage, stage-discharge routing of bridges, culverts and flap-gate culverts, and routing hydraulic linkages between main channel conveyance and overbank floodplain storage. These features make UNET an ideal tool for simulating the dynamic conditions within Novato Creek, as fluctuating tide levels in San Pablo Bay and the time dependent nature associated with storm hydrographs result in spatially and temporally variable hydraulic conditions. In addition, the relatively confined flow conditions exhibited by the Pacheco Pond-Novato Creek system are conducive to a one-dimensional analysis where connections between the main channel and storage areas are easily defined by discrete channel links. Finally, the use of UNET in a tidal environment is consistent with Corps and FEMA Guidelines (FEMA 2002). FEMA approves the use of one-dimensional unsteady flows in channel networks where flow reversals may occur and flood storage capacity must be considered.

Study Limits

The study domain used to assess the impacts of the proposed project alternatives extends from the mouth of Novato Creek upstream approximately 4 miles to the downstream face of the railroad bridge near Highway 37. Subcritical reaches are subject to downstream control, meaning that the hydraulic characteristics of a given cross section can affect stages that occur upstream. However, the distance that this effect propagates upstream is limited by channel slope and friction. This implies that if no increase in water surface elevation is calculated at the upstream study limit, then there will not be any increase in channel stage upstream of the study limit.

UNET Model Structure

UNET is an open channel network model that requires geometric data, friction coefficients, and boundary conditions as input. Using these input variable, the model solves the one-dimensional unsteady flow equations and calculates the flow magnitude and direction, water surface elevation at each cross section, and the storage characteristics of each storage area. For the impact analyses, the model geometry and boundary conditions are based on existing data.

Geometry

The study reaches include Pacheco Pond, Novato Creek, and the Bel Marin Keys V site. Network model geometries were developed by **nhc** from existing Light Detection and Radar (LiDAR), levee, and bathymetric surveys (Towill 1996). Since the model is designed to identify relative changes in hydraulic characteristics due to project features, several simplifying assumptions were made regarding Novato Creek's and Pacheco Pond's connections to adjacent areas. These include the assumption that flow from Novato Creek could only pass to the BMK V site and from Pacheco Pond through the flap gate connection. This allows for easily tracking changes in water surface elevations in Novato Creek due to project modifications by not simulating overtopping of levees into other adjacent areas such as the Antenna Fields north of Novato Creek. Furthermore, this assumption provides a conservative means to identify the project features' influence on water surface elevations.
The volume of flow overtopping the levee separating Pacheco Pond and the BMKV (at an elevation between 6 and 7 feet NGVD29) was investigated during initial sensitivity analyses. Approximately 14.4 acre-feet were calculated to flow over the levee into the BMKV site for the existing conditions geometry in Inflow Scenario A. This volume is approximately 0.6 percent of the inflowing volume to Pacheco Pond during Inflow Scenario A. Based on this analysis, weir flow over the levee was determined to be negligible with respect to the overflow volume's potential to increase flood stages.

Four geometric scenarios were developed to identify impacts on hydraulic characteristics along Novato Creek. These scenarios are summarized listed in Table 1 and graphically depicted in network schematic diagrams on Figure 2.

Water surface elevation and storage in Pacheco Pond and the Bel Marin Keys V site were simulated as storage areas in the UNET model. A lateral weir between Novato Creek and the Bel Marin Keys V site was defined to compute overflow and storage on the project site for existing conditions. From the existing LiDAR and survey data, cross sections, storage area stage-volume relationships, and lateral weir characteristics were defined. Using the LiDAR data, the Pacheco Pond storage volume between 0 and 7 feet NGVD was calculated to be 880 ac-ft. This volume is same as reported in Appendix IV in the Final Environmental Impact Report for Ignacio Industrial Park, Unit 3 (Madrone 1975) between 0 and 7 feet

MSL. Due to the ongoing changes in the terrain resulting from subsidence and channel evolution, it is not possible, nor is it necessarily required, to define present day geometric conditions precisely to identify the hydraulic impacts of the project on Novato Creek and Pacheco Pond.

The cross sections used in the model include the subtidal channel of the creek, adjacent marsh floodplain, and the existing levee structures. A cross section layout is shown in Figure 1. Top of levee surveys completed in 1996 (Towill 1996), indicate that the levee crest between Novato Creek and the Bel Marin Keys V site dips to an elevation of approximately 5.6-ft, NGVD 29, at a point approximately 1000 feet downstream from the Bel Marin Keys South Lagoon navigation lock. Overtopping of this levee was observed by Bel Marin Keys residents during the February 1998 flood event. Levee surveys of the Pacheco Pond outlet channel reveal low points at 5.6 and 6.7 ft NGVD 29. Based on these data, the baseline geometric condition considers the following features:

- Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow from Pacheco Pond to Novato Ck;
- 100-ft wide lateral weir at 5.6-ft, NGVD 29 for pond overflow into Novato Creek on Leveroni Parcel
- 1000-ft wide lateral weir at 6.7-ft, NGVD 29 for pond overflow into Novato Creek on Leveroni Parcel;
- 300-ft wide lateral weir at 5.6-ft, NGVD 29 for Novato Ck overflow to BMKV site approximately 1000 feet downstream of BMK community.

Table 1. Novato Creek Geometric Scenarios

Scenario	Model Conditions
Scenario 1: Existing Novato Creek and Pacheco Pond Network - **Evaluates the interaction between Pacheco Pond and Novato Creek for existing conditions**	Model Elements • **Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow from Pacheco Pond to Novato Ck;** • **100-ft wide lateral weir at 5.6-ft, NGVD 29 for Pacheco Pond overflow to Novato Creek on Leveroni parcel** • **1000-ft wide lateral weir at 6.7-ft, NGVD 29 for Pacheco Pond overflow to Novato Creek on Leveroni parcel** • **300-ft wide lateral weir at 5.6-ft, NGVD 29 for Novato Ck overflow to BMKV site approximately 1000 feet downstream of BMK community**
Scenario 2: No Pacheco Pond Outlet to Novato Creek and a Design Breach along BMKV -	Model Elements • **Pacheco Pond disconnected from Novato Creek;** • **right bank levee removed downstream of BMK Development** • **right bank floodplain expanded laterally by 1000-ft downstream of BMK Development to reflect opportunity for overflow into restored tidal marsh** • **600-acre tidal marsh modeled as storage area with hydraulic connection through new breach channel to lower Novato Creek.**
Scenario 3: Pacheco Pond Outlet to Novato Creek and a Design Breach -	Model Elements • **100-ft wide lateral weir at 5.6-ft, NGVD 29 for Pacheco Pond overflow to Novato Creek on Leveroni parcel** • **1000-ft wide lateral weir at 6.7-ft, NGVD 29 for Pacheco Pond overflow to Novato Creek on Leveroni parcel** • **Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow to tidal marsh** • **right bank levee removed downstream of BMK Development** • **right bank floodplain expanded laterally by 1000-ft downstream of BMKV swale to reflect opportunity for overflow into restored tidal marsh** • **600-acre tidal marsh modeled as storage area with hydraulic connection through new breach channel to lower Novato Creek.**
Scenario 4: No Pacheco Pond Outlet and No Design Breach along BMKV -	Model Elements • Connections between Pacheco Pond and Novato Creek Removed.

Hydraulic parameters in Pacheco Pond were estimated from geometric Scenarios 1, 3, 5, and 6. In Alternatives 1, 2, and 3 Pacheco Pond drains to the BMKV site and the outlet to Novato Creek is closed. Alternatives 1 and 3 were simulated by Geometric Scenarios 5 and Alternative 2 was simulated by Geometric Scenario 6. These scenarios are summarized in Table 2.

Scenario	Model Conditions
Scenario 5: Pacheco Pond Configuration for Alternatives 1 and 3 - **Evaluates an expanded Pacheco Pond with a flap gate outlet to the tidal marsh**	Model Elements • **Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow from Pacheco Pond to tidal marsh;** • **Pacheco Pond expanded to increase the pond surface area by 74 ac.**
Scenario 6: Pacheco Pond Configuration for Alternative 2 - **Evaluates an expanded Pacheco Pond with an adjacent seasonal marsh storage area, flow controlled by weir and flap gate structure**	Model Elements • **100 -ft weir controls flow from Pacheco Pond to seasonal wetland;** • **Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow from seasonal wetland to tidal marsh** • **Seasonal wetland surface area 135 ac** • **Pacheco Pond surface area expanded by 32 ac.**

Boundary Conditions

Boundary conditions were developed at the upstream and downstream study limits. Two inflow scenarios were modeled loosely representing the 10- and 100-year flow events for existing conditions. Hydrologic Scenarios A and B use published 10-year and 100-year flood event hydrographs, respectively, from two previous Corps of Engineers studies (Corps of Engineers 1987, PWA 1998).

Tide measurements taken at the mouth of the Petaluma River were utilized to develop time series of tidal stage hydrographs at the mouth of Novato Creek. These data, completed as part of the San Francisco Airport runway expansion dredge material disposal studies, consist of tidal stage measurements recorded at 10-minute increments for approximately one month duration (14 June - 17 July 2000). Previous studies of Novato Creek indicate negligible differences between Novato Creek and Petaluma River tidal stage characteristics (PWA, 1998). To conservatively estimate tidal conditions during flood events, the tide data were modified in two ways to reflect extreme tidal conditions that occur during significant flood events. The first modification was to increase the observed peak tidal stage by one foot to reflect extreme high tides due to low atmospheric pressure and wind setup in the region. This is equivalent to coincident tidal stage boundary conditions frequently used by the Corps of Engineers and the FEMA for flood control design or flood hazard mapping studies on tidally influenced streams and rivers in the San Francisco Bay Area. The resulting peak tide was calculated to be 5.75 ft NGVD 29, 0.25 feet lower than the 10-year peak tide. The second modification was to truncate the low tide elevation at the mean tide level to represent limits on low tide excursion due to extreme regional, basin-wide runoff conditions (Anderson et al, 2000). The resulting tidal boundary condition is shown in Figure 3.

Theoretically, there are infinite phasing combinations between the peak tide elevation and the peak discharge hydrographs. To simplify the analysis, Pacheco Creek and Arroyo San Jose hydrographs were phased to be coincident with the higher high water tidal stage for all model runs. However, the phasing of the Novato Creek hydrograph was varied to investigate the effect of lag times on system. Due to the larger watershed dimensions, the peak discharge from Novato Creek would be expected to lag the Pacheco Pond peak discharges. Novato Creek hydrographs were developed using three different lag times relative to the peak hydrograph from the Pacheco Pond watershed: 0-hour lag time (i.e. coincident with the higher high water tide stage and other hydrographs), 6-hour lag time (i.e. 6 hours behind other hydrographs), and 12-hour lag time. The adjustment of phasing was only relevant to the model runs that evaluated the existing conditions, as Pacheco Pond flows are routed away from Novato Creek for all project condition scenarios.

Loss Coefficients

Channel friction is expressed in UNET using Manning's equation. The Manning's roughness coefficient was set at 0.02 for the subtidal channel and 0.04 for the salt marsh benches. These values were adopted from calibrated UNET models of Sonoma Creek developed as part of the mitigation planning for the San Francisco Airport runway expansion studies.

<u>Model Scenarios</u>
Four geometric scenarios were run for each of the hydrologic flow scenarios to assess project impacts on Novato Creek. Pacheco Pond was connected to Novato Creek in scenarios 1 and 3. Two additional geometric scenarios of Pacheco Pond (scenarios 5 and 6) were defined to evaluate the impacts to Pacheco Pond water surface elevations by the project alternatives. In these scenarios the flap gate connection between Pacheco Pond and Novato Creek was closed, thus identifying the effects of diverting all flow to Bel Marin Keys V project site. However, it should be noted that a new water management scenario envisioned by the project includes dual use of the existing and new outlets to enhance water quality in Pacheco Pond. Project Alternatives 1 and 3 were modeled as one scenario and Alternative 2 was modeled as a separate scenario. The conditions for Pacheco Pond draining directly to the Bel Marin Keys V site are modeled as Scenarios 5 and 6, respectively. The characteristics of the geometric model scenarios are summarized in Table 2. Schematic diagrams of the hydraulic connections and storage areas are shown in Figure 2.

Table 2. Geometric Model Scenarios

Scenario	Description
1	Existing conditions Novato Creek connected to Pacheco Pond. No design breach between Novato Creek and BMKV
2	Alternative 2 No connection between Novato Creek and Pacheco Pond Design breach between Novato Creek and BMKV
3	Novato Creek connected to Pacheco Pond. Design breach between Novato Creek and BMKV
4	No connection between Novato Creek and Pacheco Pond No design breach between Novato Creek and BMKV
5	No connection between Novato Creek and Pacheco Pond Pacheco Pond expansion Pacheco Pond outlet to BMKV as described in Project Alternatives 1 and 3
6	No connection between Novato Creek and Pacheco Pond Pacheco Pond connected to expanded pond and seasonal wetland as described in Revised Alt. 2 Seasonal Wetland outlet to BMKV as described in Revised Alternative 2

<u>Model Results</u>
Summarized below are the model results for the hydraulic routing analyses. Values presented in the results section are intended for comparison purposes to identify relative changes in hydraulic parameters between project elements (i.e. Pacheco Pond removal and/or design breach). Comparisons of water surface stage, velocity, and flow were made between Geometric Scenarios for a each flow condition.

Project Impacts to Novato Creek Stage -The project's impact on stage was evaluated by reviewing time series of computed stage data at three locations along Novato Creek; the proposed design breach location (Section 2.8), downstream of the Pacheco Pond outlet (Section 8 ds), and at the upstream model cross section immediately downstream of Highway 37 (Section 10). Scenario 1, which is equivalent to existing conditions on Novato Creek with a flap gate connection to Pacheco Pond and no design breach to the Bel Marin Keys V site, was used as the baseline condition from which comparisons with Scenarios 2 through 4 were made. The comparisons are described below.

- **Impact of levee breach** - Addition of the design breach to the baseline condition modeled in Scenario 3 produces negligible changes in water surface elevations (i.e. 0.25 feet or less) at

Sections 2.8, 8 ds, and 10. The time series histories are shown on Figures 4 and 5 for Inflow Conditions A and B, respectively.

- **Impact of rerouting Pacheco Pond connection to Bel Marin Keys V project site** – Removal of Pacheco Pond in Scenario 2 reduced the flow into Novato Creek and increased the magnitude of flow recession during ebb tides. A small (<0.25 foot) reduction in peak water surface elevation was also computed at all points on Novato Creek. These results are summarized in Table 3.

The computed stage for Scenarios 1 and 3, Pacheco Pond connected to Novato Creek, are similar at Sections 2.8, 8 ds, and 10 as are Scenarios 2 and 4, without Pacheco Pond connected to Novato Creek. The rapid stage recession computed in Scenarios 2 and 4 results from the reduced flow into Novato Creek from Pacheco Pond. These observations hold true for both Inflow Condition A and B.

Table 3. Summary of Maximum Stages

Scenario	Flow Condition A			Flow Condition B		
	Sec 2.8 Stage, ft	Sec 8 d/s Stage, ft	Sec 10 Stage, ft	Sec 2.8 Stage, ft	Sec 8 d/s Stage, ft	Sec 10 Stage, ft
1	5.69	6.13	6.55	5.69	7.26	8.09
2	5.64	6.12	6.54	5.69	7.00	7.98
3	5.64	6.12	6.54	5.64	7.13	8.03
4	5.69	6.13	6.52	5.68	7.04	7.99

Project Impacts to Novato Creek Velocity - Impacts due to Pacheco Pond and the design breach on channel velocity were assessed in a similar manner as the stage impacts, and are summarized below.

- **Impact of levee breach** – The levee breach connection to the restored tidal wetland in Scenarios 2 and 3 shows a large change in the computed velocity time series at Section 2.8, located immediately downstream of the levee breach, when compared with Scenario 1. Higher magnitude ebb and flood velocities are created by increasing the tidal prism of the restored tidal wetland and connecting this tidal prism to Novato Creek. The levee breach has no appreciable effect on velocity magnitudes upstream of the design breach at Sections 8 ds and 10. A summary of the peak velocities calculated for each scenario is provided in Table 4. Time series are shown in Figure 6 and 7 for flow scenarios A and B, respectively.

- **Impact of removing Pacheco Pond** – Removal of Pacheco Pond flood flows to Novato Creek has a negligible impact of peak velocities (less than 0.5 fps) at Sections 8 and 10. The velocity time series at these locations indicate a more rapid recession of velocities when Pacheco Pond flows are removed from the Novato Creek system.

Table 4. Summary of Maximum Velocity

Scenario	Flow Condition A			Flow Condition B		
	Sec 2.8 Vel, fps	Sec 8 d/s Vel, fps	Sec 10 Vel, fps	Sec 2.8 Vel, fps	Sec 8 d/s Vel, fps	Sec 10 Vel, fps
1	3.72	4.04	4.24	4.93	5.40	5.85
2	5.30	3.20	4.41	5.33	5.47	5.97
3	5.33	3.91	4.41	5.32	5.47	5.97
4	3.53	3.31	4.26	4.78	5.26	5.88

Project Impacts to Novato Creek Flow Rate - Impacts due to Pacheco Pond and the design breach on channel flow rate were assessed in a similar manner as the stage impacts and velocity impacts, and are summarized below.

- **Impact of levee breach –** As shown in Figures 8 and 9, the levee breach has no appreciable effect on flows at Sections 8 ds and 10. Downstream of the design levee breach (Section 2.8), the computed flow rate for both ebb and flood tide conditions on Novato Creek increases due to the draining and filling of the tidal prism in the proposed tidal wetland.

- **Impact of removing Pacheco Pond –** Removal of Pacheco Pond flows reduces the peak flow on Novato Creek at Section 2.8 and 8 ds, as summarized in Table 5. These reductions in flow and volume are shown in the flow time series histories on Figures 8 and 9.

Table 5. Summary of Peak Novato Creek Flow

	Flow Condition A			Flow Condition B		
Scenario	Sec 2.8 Flow, cfs	Sec 8 d/s Flow, cfs	Sec 10 Flow, cfs	Sec 2.8 Flow, cfs	Sec 8 d/s Flow, cfs	Sec 10 Flow, cfs
1	3230	2180	1740	4710	3870	3740
2	5180	1760	1740	5910	3490	3740
3	5180	2140	1740	5180	3810	3740
4	3270	1770	1740	4460	3480	3740

Project Impacts to Pacheco Pond Stage – The stage of Pacheco Pond was computed for all geometric and hydrologic scenarios. The proposed rerouting and expansion of Pacheco Pond substantially reduces the peak water surface elevation within Pacheco Pond (Table 6). Reducing stage in Pacheco Pond would improve the drainage of Ignacio Business Park and other low-lying areas adjacent to lower Arroyo San Jose, such as the nearby trailer park. The magnitude and extent of this improvement, however, was not quantified in this analysis.

Table 6. Peak Water Surface Elevations in Pacheco Pond (ft, NGVD 29)

Case	Scenario A	Scenario B
Existing	6.4	7.6
Alternative 1 & 3	4.5	7.2
Revised Alternative 2	4.6	6.3

The volume of water overtopping the Bel Marin Keys V levee from Novato Creek during the Scenario 1 (existing condition) Flow Condition A, which loosely represents the current 100-year Novato Creek flood, is 5 ac-ft. The duration of overtopping is less than 2 hours and has a peak discharge over the levee top of less than 60 cfs. The flow overtopping into the BMKV site during Scenario 1 Flow Condition A is less than 0.2 percent of the inflow hydrograph at the upstream Novato Creek boundary (Section 10).

Conclusion

The proposed levee breach and potential diversion of Pacheco Pond inflows reduces peak water surface stages in Novato Creek. The proposed tidal wetland connection to Novato Creek slightly increases channel velocity downstream of the proposed levee breach. Rerouting of Pacheco Pond reduces the duration of high velocities above the levee breach during the infrequent flood flows (approximately 1 in 10 or 100 years) modeled for this study. As described in the memorandum titled *Novato Creek Geomorphic and Hydraulic Modeling Technical* (**nhc** 2002b) hydraulic properties associated with daily tidal cycles are the dominant influence on tidal channel morphology. The proposed project will have no measurable impact on tidal hydraulics upstream of the design breach and will increase the tidal prism downstream of the design breach. This increase in tidal prism results in an increase in the channel dimensions downstream of the breach. The results indicate a reduction in stage on Novato Creek for all project conditions. The project alternatives all resulted in a reduction in flood stage on Novato Creek. The volume of overtopping into the BMKV levee from Novato Creek under existing conditions is negligible, and has no measurable impact on flood stage reduction on Novato Creek.

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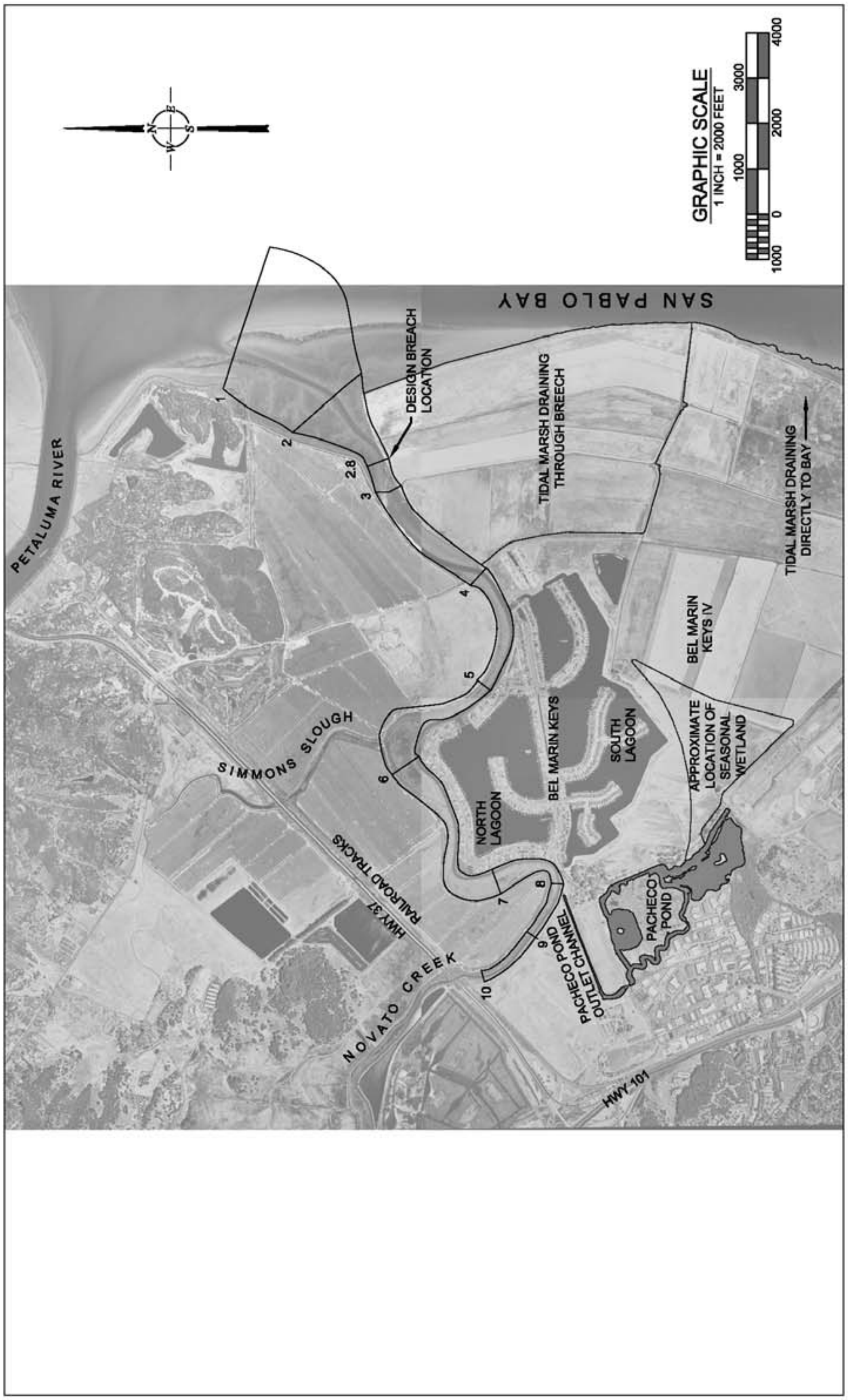


nhc
Bel Marin Keys
Hydraulic Routing Analysis

Figure 1
Study Area Map
09/02

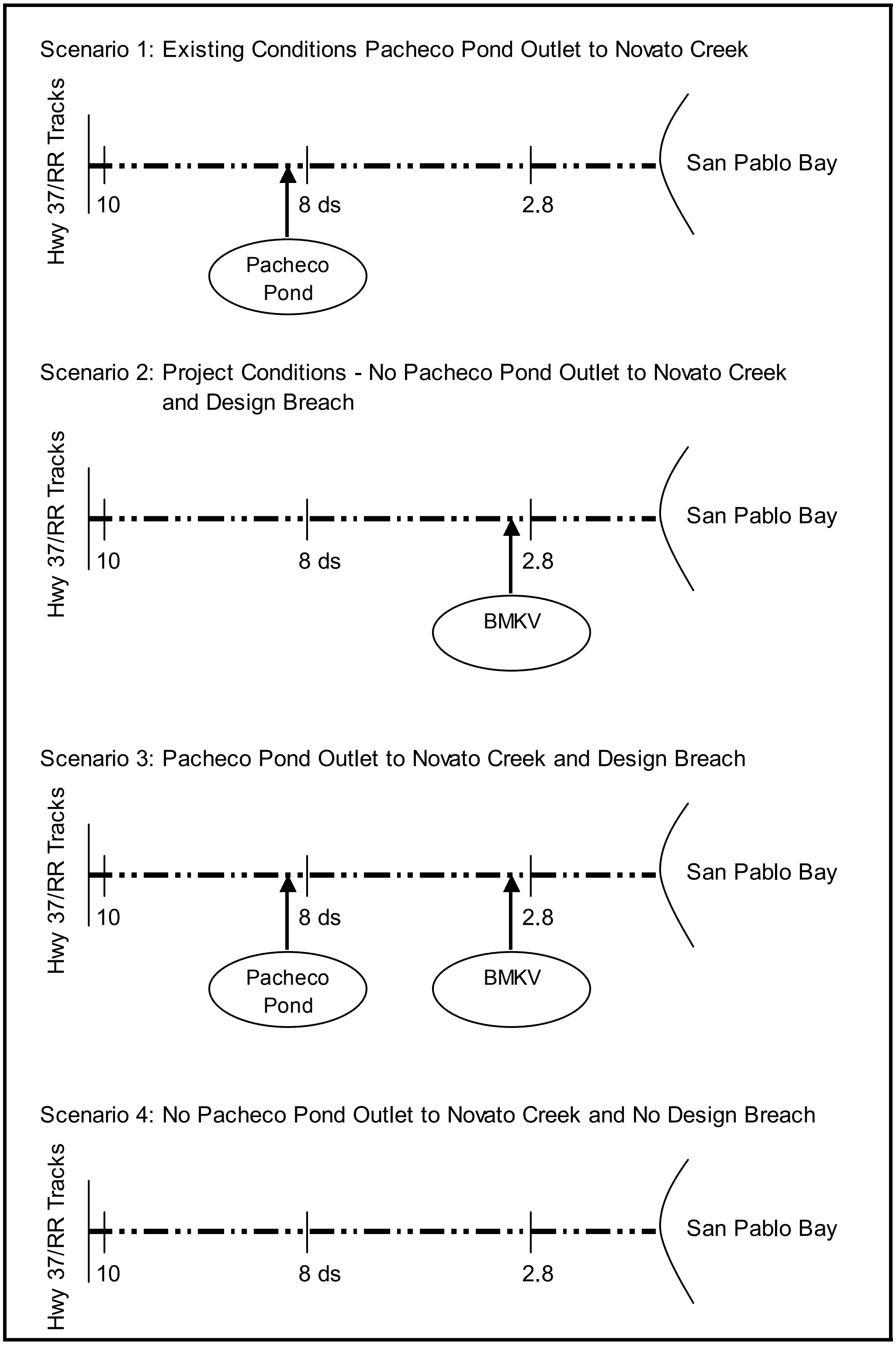


Figure 2. Geometric Scenario Schematic Diagrams

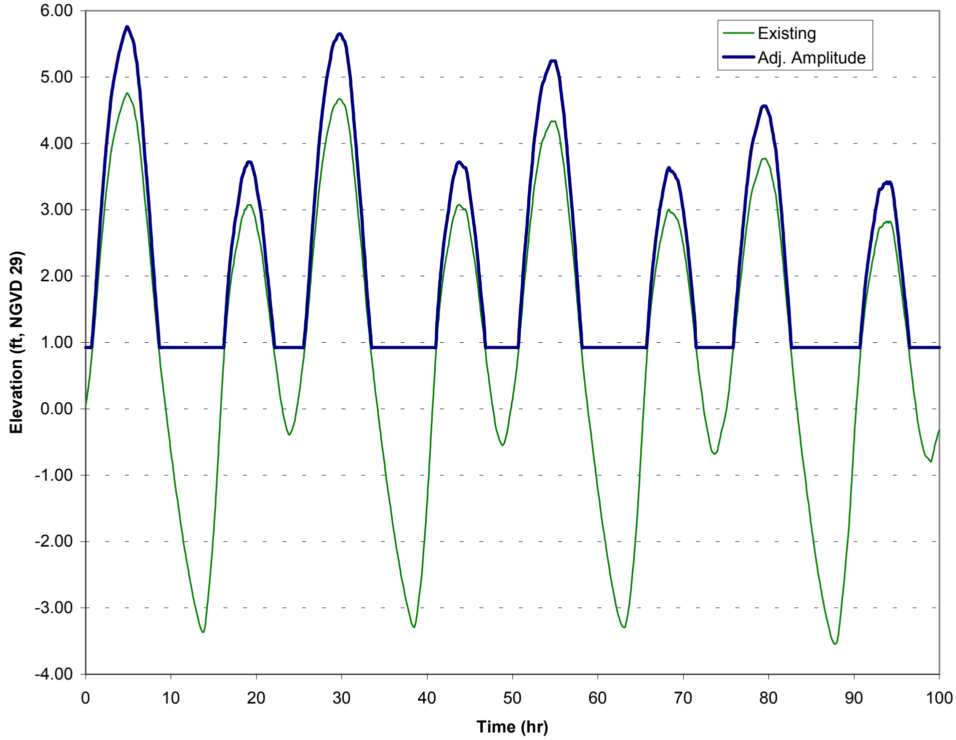
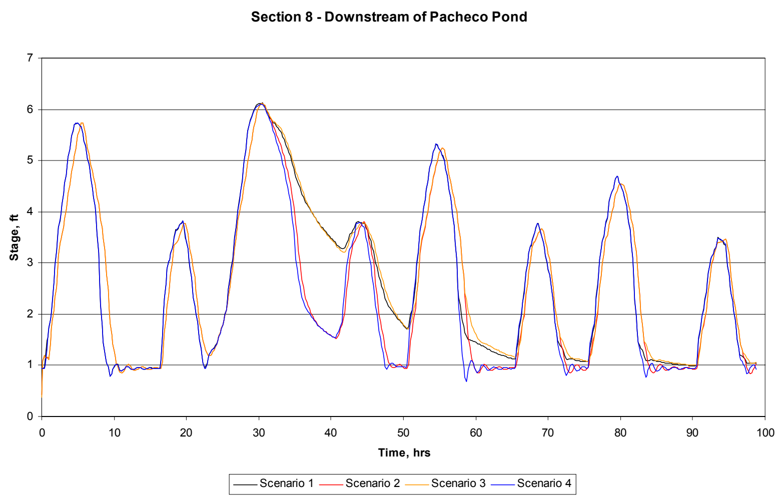


Figure 3. Tidal Boundary Condition



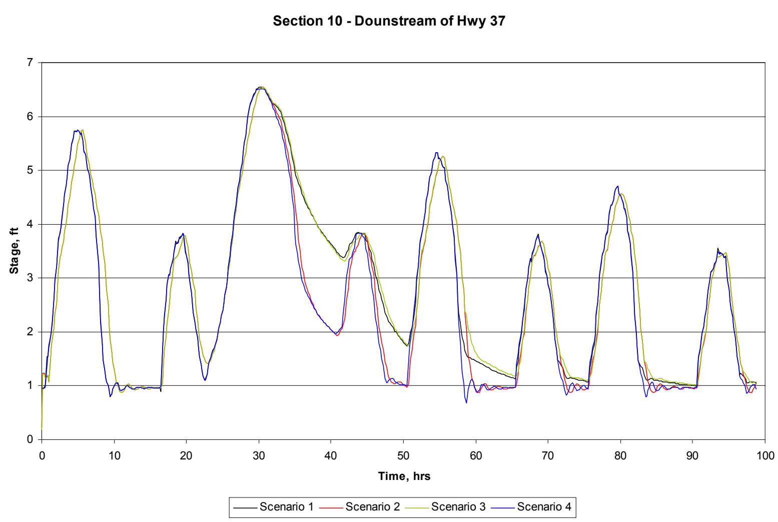
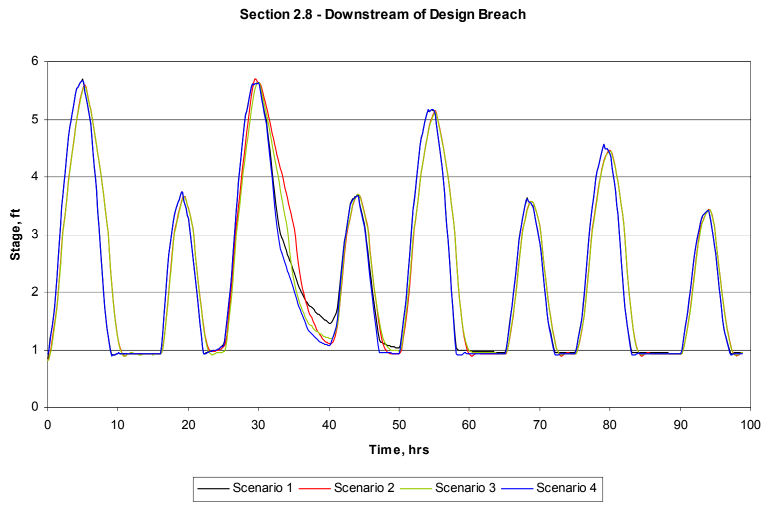
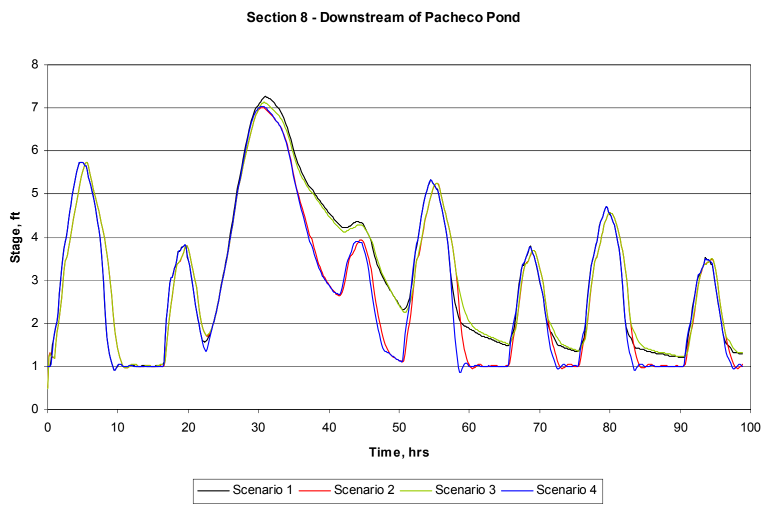


Figure 4. Stage Time Series Histories for Flow Condition A





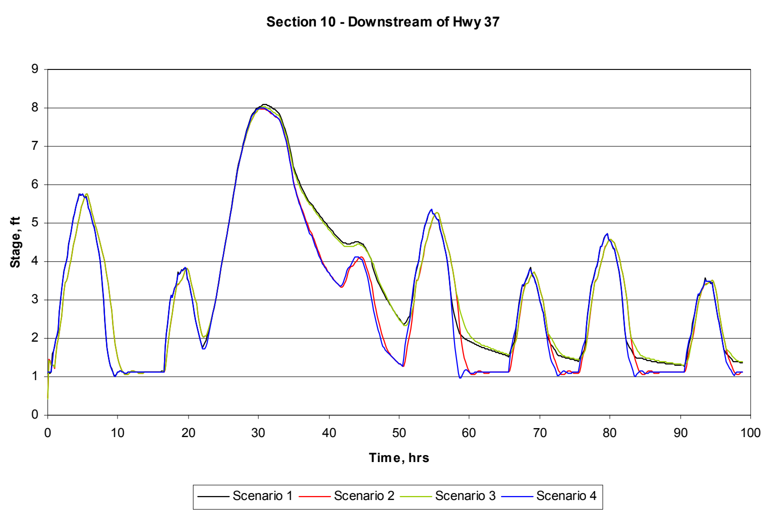
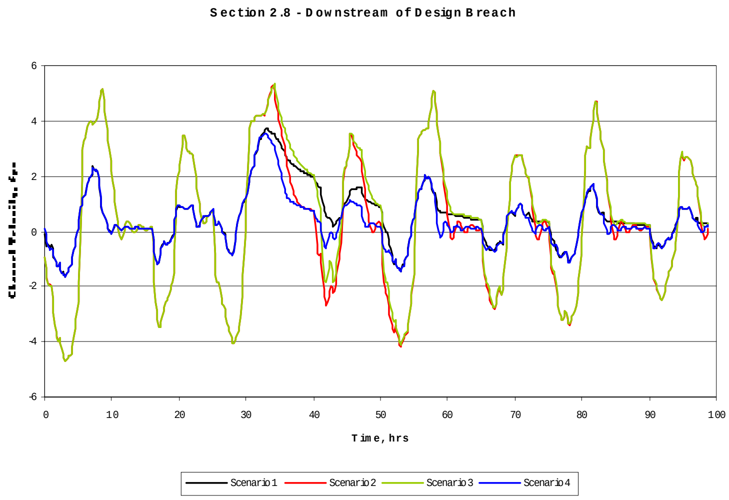
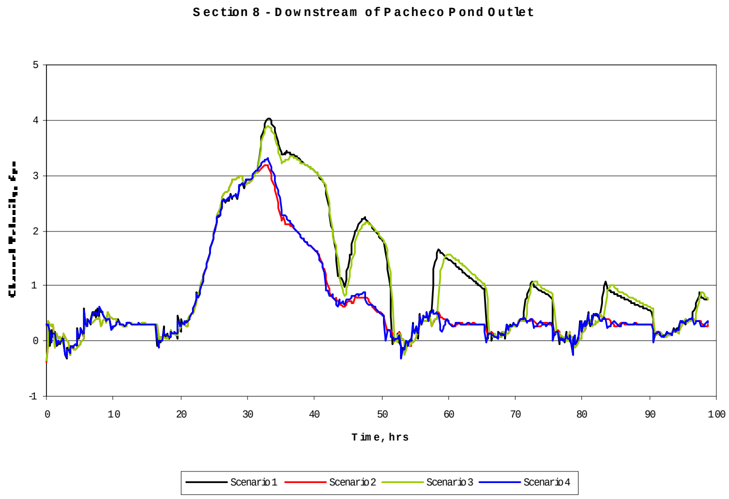


Figure 5. Stage Time Series Histories for Flow Condition B





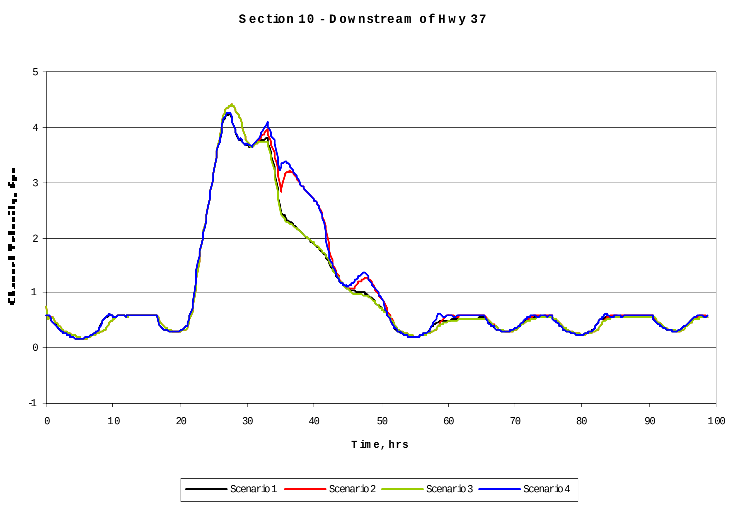
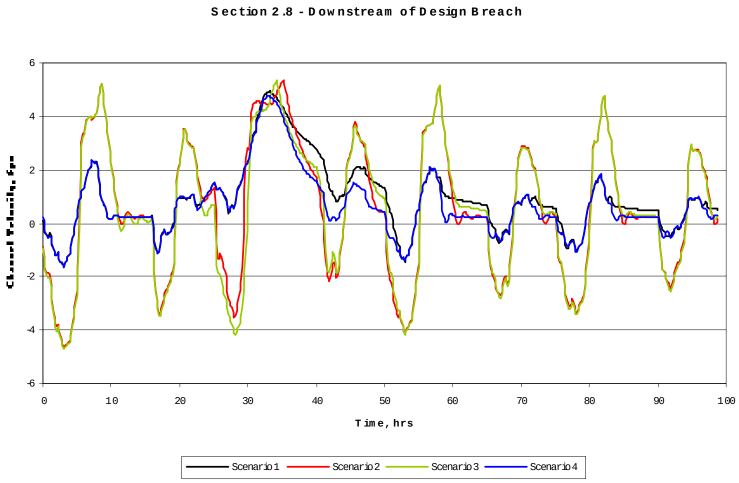
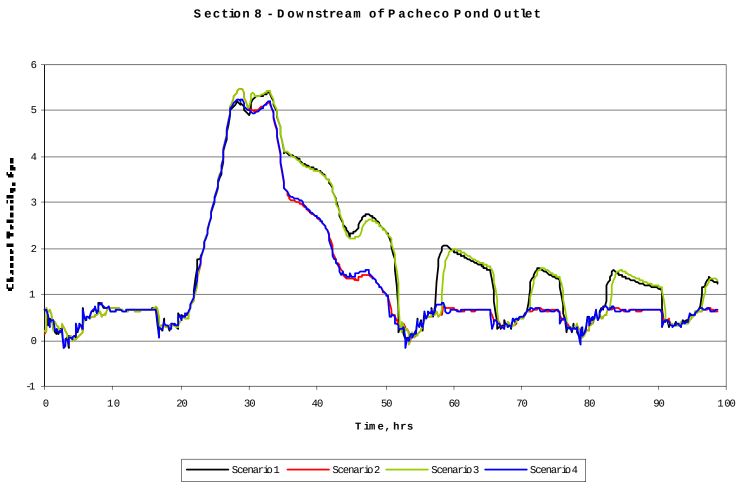


Figure 6. Velocity Time Series Histories for Flow Condition A





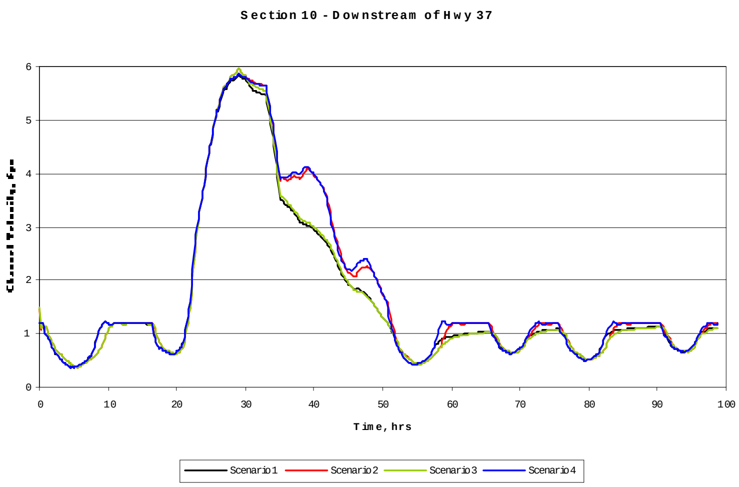


Figure 7. Velocity Time Series Histories for Flow Condition B

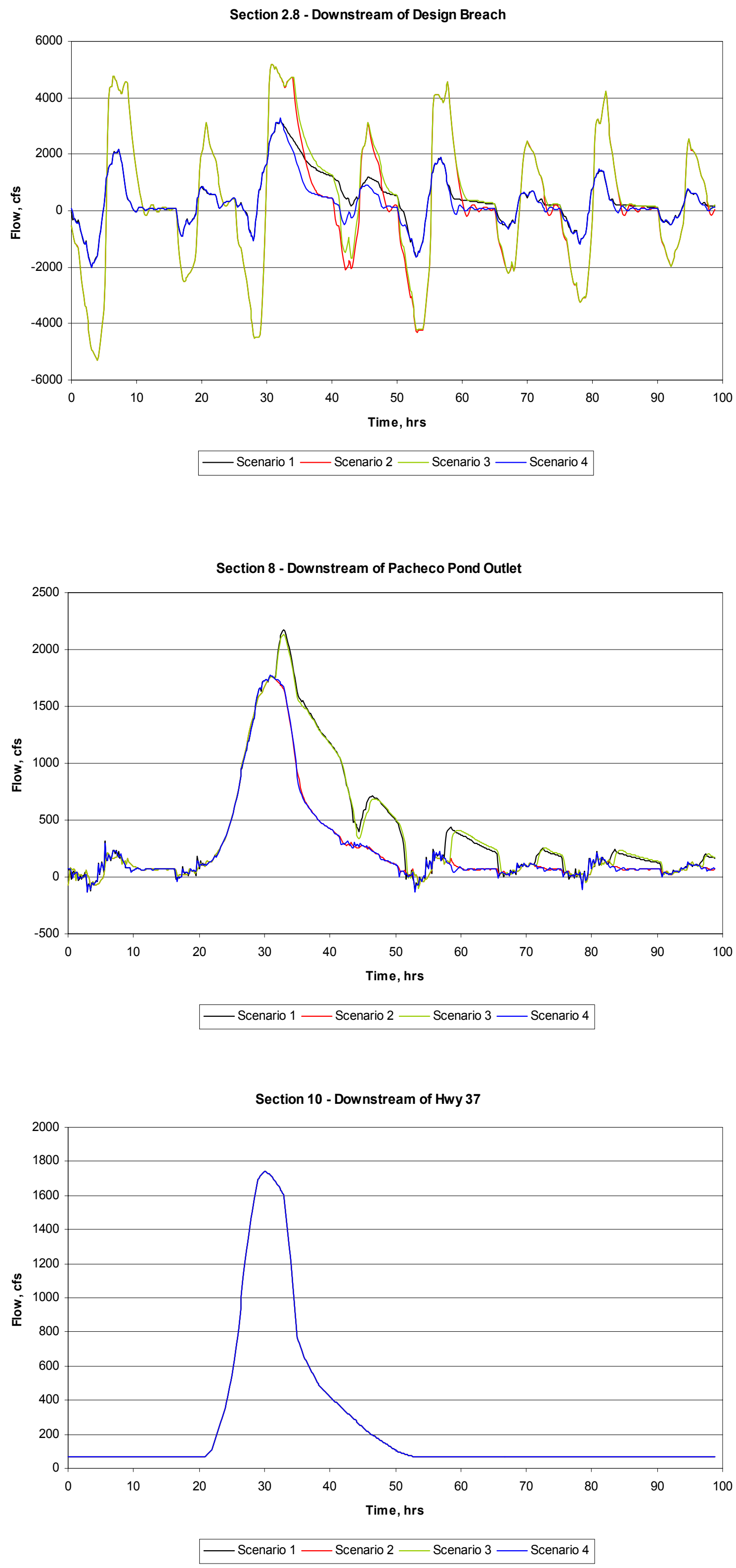
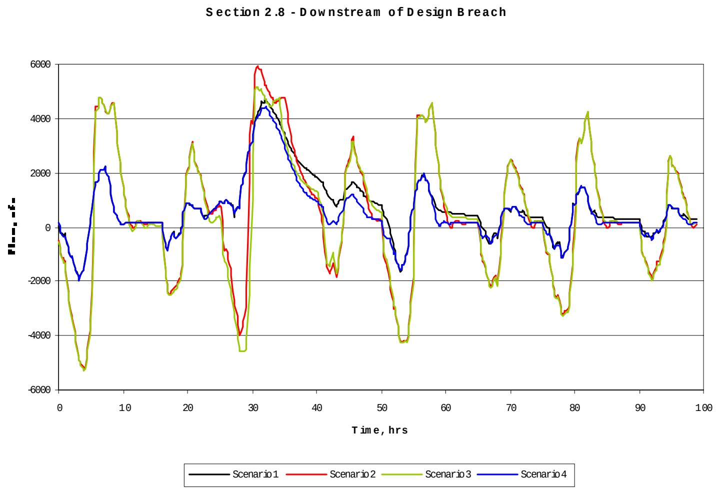
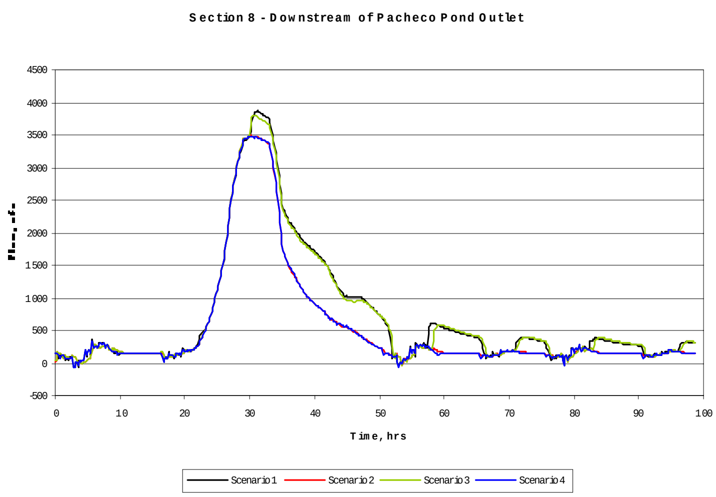


Figure 8. Hydrographs for Flow Condition A





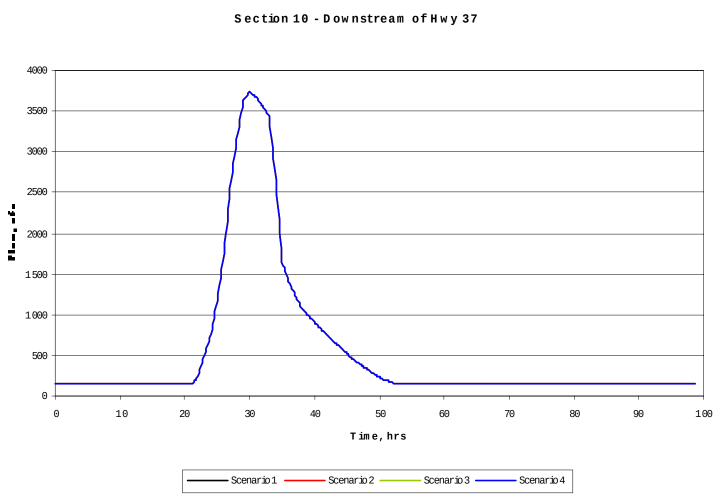


Figure 9. Hydrographs for Flow Condition B

Memorandum

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Date:	October 14, 2002	Project: 50283
To:	Rich Walter	
Company/Agency:	Jones & Stokes	
From:	Brad Hall	
Subject:	Bel Marin Keys EIR Background Study	

Novato Creek Geomorphic and Hydraulic Modeling

The Bel Marin Keys (BMK) conceptual design plans call for a breach in the Novato Creek containment levee to provide tidal exchange to a proposed marsh basin near the mouth of the creek. The addition of 400 to 600 acres of tidal marsh to the existing system would enlarge the tidal prism of the creek and increase the tidal discharge in the channel reach between the breach and San Pablo Bay. To better understand the effects of the proposed breach, an unsteady hydraulic model of Novato Creek was developed and tested. Also, an empirical investigation of the surrounding tidal mudflat channel and shoals at the mouth of the creek was implemented. This memorandum discusses the background, methodology, and general results of these investigations.

Novato Creek Modeling Approach

UNET, a one-dimensional hydraulic model developed by the U.S. Army Corps of Engineers, was used to determine channel velocities in Novato Creek from tidal exchange. The marsh basin was specified as a storage area connected to the creek by the levee breach. The time series tide data used for the analysis were measured by ADEC and obtained at the mouth of the Petaluma River. Measurements were taken at 10-minute intervals over a full month period during the summer of 2000. The data was adjusted slightly so that mean sea level of the data correlated with the observed mean sea level of San Pablo Bay at the mouth of the Petaluma River (0.62 feet NGVD). No adjustments were made to the data to account for frequency or lag effects.

Cross sections for Novato Creek were developed from an algorithm that related slough channel top width to channel side slope and base width. This relationship was created by Northwest Hydraulic Consultants using data from various sloughs and channels located in the San Francisco Bay area, including Novato Creek. The equations relating the hydraulic parameters were of the form:

$$m = m_1 T^{m_2} \tag{1}$$

$$b = b_1 T \tag{2}$$

where m and b are the typical channel side slope and base width, respectively, associated with a top width T. The constants m_1, m_2, and b_1 were determined to be 0.13, 0.67, and 0.5, respectively, such that the hydraulic characteristics of the predicted and observed cross sections were as similar as possible. Equations 1 and 2 were then used to estimate the existing and likely future geometries of Novato Creek during the hydraulic and geomorphic modeling processes. Top widths on Novato Creek and other tidal sloughs adjacent to San Pablo Bay were measured from infrared aerial photographs taken by Air Flight Services in September of 2000.

The modeling procedure for estimating the widening of Novato Creek was an iterative process. Using the 30-day tide data and UNET, channel velocities and water surface profiles were calculated in the creek. This information was used to estimate shear stresses that developed along the channel boundary at each time step. Each value of computed shear stress, in turn, was used to estimate the incremental erosion that would take place along the channel according to the empirical equation:

$$E = M \frac{\tau - \tau_{cr}}{\tau_{cr}} \tag{3}$$

where E is the erosion rate, τ is the average boundary shear stress at a cross section, τ_{cr} is the critical shear stress for erosion, and M is an erosion coefficient.

A wide range of values is presented in the literature for the erosion coefficient. The values ranged from a low of 0.003 g/m^{2}sec found by Mehta et al. (1994) to a high of 5.0 g/m^{2}sec calculated by Ariathruai and Arulanandan (1978). In an effort to establish a suitable value for M, erosion data were obtained from slough channels between the years of 1994 to 1998 at Sonoma Baylands (Phillip Williams and Associates, 1999) and 1997 to 1999 at the Oro Loma Marsh (Lenington, 2001). From analysis of the data, an erosion constant of M = 0.015 g/m^{2}sec was established, which produced erosion rates of about 0.5 to 3 feet per year in channels with peak velocities between 3.5 and 6 feet per second.

Critical shear stress is a function of many variables including the physical and chemical properties of the eroded soil, and density and type of vegetative cover.

A midrange value of τ_{cr}=0.75 N/m^2 was adopted as a reasonable compromise. This value also produced modeling results that agreed well with the stable channel threshold velocity range of 2.5 to 3 feet per second.

Channel roughness in UNET is modeled using the Manning Equation and an associated Manning's 'n' coefficient. The coefficient accounts for hydraulic energy losses due to friction, which are responsible for the phenomenon of tidal muting. An appropriate value for Manning's n was developed using both published values and an empirical calibration of the Skaggs Island UNET model. Weisman et al. (1989) calculated coefficient values that ranged between 0.0125 and 0.0202. Chow (1959) listed values of 0.020 to 0.025 for channels made of fine silts and clays. Barnes (1967) suggested a value of *n*=0.026 for the Indian Fork River, which has a clay channel and a flat slope. Leopold et al. (1993) found somewhat higher roughness values for local tidal channels that ranged between 0.028 and 0.063.

For this study, Manning's n was determined by trial and error using tide data collected by ADEC (2000) and Warner and Schoellhamer (1999). Both data sets include tide data collected at the lower end of Sonoma Creek and at Hudeman Slough at the northern end of Skaggs Island. The data indicate that full tidal exchange occurs at both stations, with a lag time of about 30 to 40 minutes. With this in mind, a UNET model of the existing slough network around Skaggs Island was developed specifically to calibrate Manning's n for the system. By trial and error, it was observed that tidal muting disappeared in the model when using a roughness coefficient of n=0.02. This value was, therefore, defined as the slough channel roughness coefficient. The marsh plains were assumed to be much rougher than the channels due to dense vegetation and variable topography. A value of n=0.04 was assigned to these areas according to Barnes (1967), Chow (1959), and engineering judgment. UNET model results were relatively insensitive to the value of the marsh plain roughness.

Mudflat Modeling Approach

To estimate the potential effects of the proposed restoration on the mudflats, or shoals, at the mouth of Novato, a study of existing mudflat channels was performed. This study consisted of using bathymetric data and newly established transects in established mudflat channels around the bay to develop a relationship between mudflat channel top width and upstream tidal prism volume.

Typical mud flat cross sections were selected where the average mud flat elevation was approximately -0.5 m, NGVD 29. Tidal prism volumes in the upstream basins were estimated using the planform area of the observed channels multiplied by the vertical range in tides (MHHW to MLLW). Figure 1 presents the relationship observed between mud flat channel width and upstream

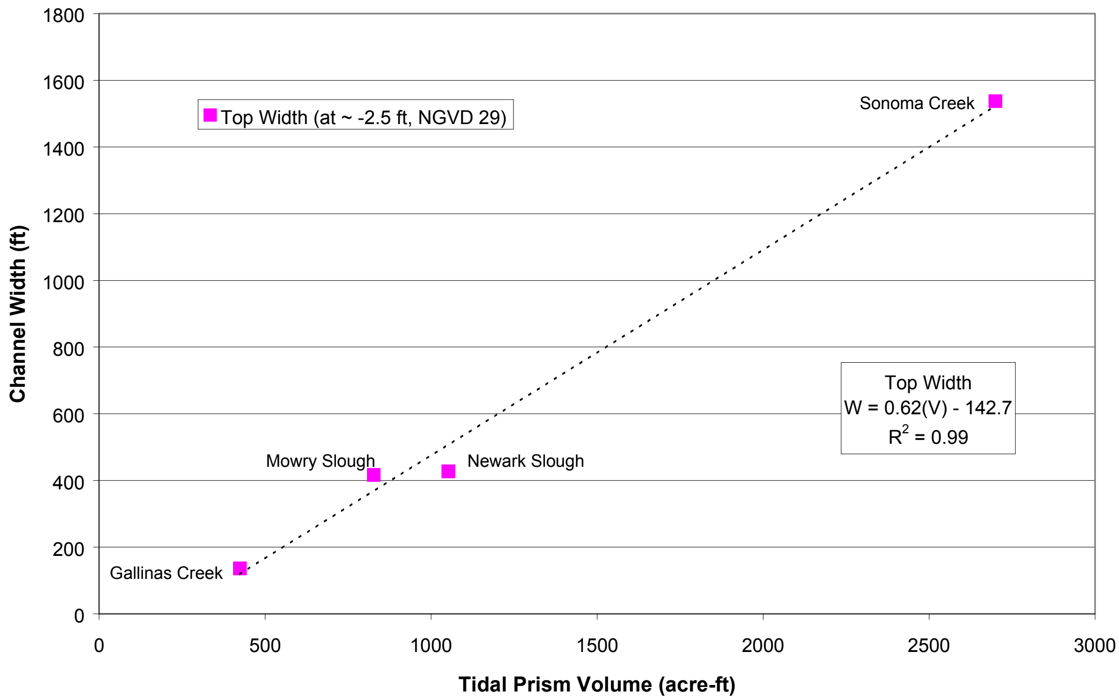

Figure 1. Mudflat channel width as a function of upstream tidal prism volume.

tidal prism volume. A best-fit line was added to the data points to correlate mud flat channel size to basin volume. Because the relationship presented in Figure 1 is linear, an increase in basin volume should result in a proportional increase in mudflat channel top width. The estimated volume of the proposed marsh basin is about 800 acre-feet at MHHW, assuming equilibrium marsh plain elevations. According to Figure 1, this corresponds to a mudflat channel width increase of between 250 to 350 feet. The total length of the mudflat channel is approximately 2000 feet.

Modeling Results and Discussion

The hydraulic and geomorphic modeling of the lower Novato Creek suggested that the 140-foot wide channel downstream of the breach would increase by 10 to 40 feet in width and about a half to one foot in depth due to the addition of the proposed marsh basin connection. This corresponds to about 2 to 5 acres of eroded marsh flood plain. The shoal analysis predicted a loss of approximately 10 to 15 acres of existing mudflat due to the basin connection, which would likely occur along the sides of the mudflat channel. The invert elevation of the mudflat channel may also decrease slightly due to the addition of the marsh basin. The marsh restoration project is expected to develop 400 to 600 acres of new tidal marsh connected to Novato Creek and over 50 acres of new fringe mud flat. Therefore, these impacts are considered to be less than significant.

The erosion of the Novato Creek channel downstream of the levee breach would occur slowly over time due to increases in flow and channel velocity. The hydraulic model predicted a peak tidal flow increase from an existing 1500 cfs to between 3000 and 5000 cfs with the breach in place. Velocity increases will be most apparent immediately downstream of the breach where the channel width is most constricted. Existing peak tidal velocities of 2 feet per second will increase to 4 to 6 feet per second in some sections for existing Novato Creek channel configurations. This increased velocity is contained to the subtidal channel section, and leads to the predicted widening of the lowermost tidally influenced reach of Novato Creek. Because the perimeter levees are set back from the main channel near the mouth of the creek, and because the flow is forced over an elevated and highly roughened flood plain during high tides, the velocity increases near the levee due to the breach would be negligible or zero. Therefore, the increase in channel velocity would not threaten the structural integrity of the confining levees.

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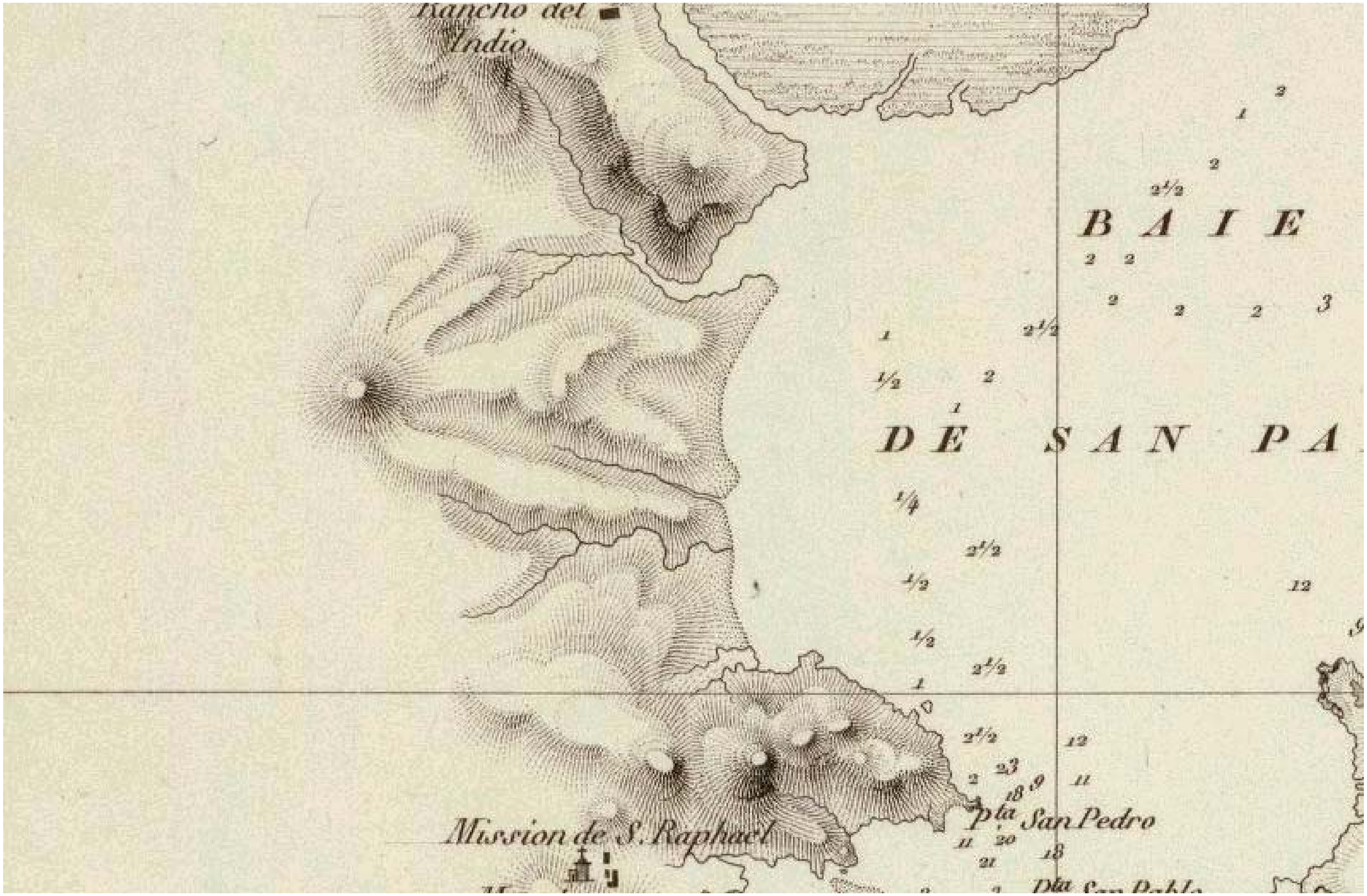
Jones & Stokes

Ponding Capacity of Non-Tidal Areas, Revised Alternative 2 DRAFT - Conceptual Design Estimate All Elevations in NGVD; Capacity in Acre-Feet			
Ponding Capacity of Seasonal Wetland	**Swale**	**Seasonal Wetland in Swale**	**Upland in Swale**
Top elevation	5.00	0.00	1.50
Bottom elevation	-1.50	-1.50	0.00
Acres (90% of swale)	348	140	208
Assumed Average Bottom Elev. (50/50: top/bottom)	NA	-0.75	0.75
Ponding Capacity to 1.5'	471	315	156
Ponding Capacity to 3.5' (top of assumed 24" culvert)	1168	595	573
Possible Maximum (to 5' NGVD)	1690	805	885
Delta (per foot > 1.5')	348		
10% of swale assumed not to pond (levees, areas near BMK blvd.)			
Ponding Capacity of Expanded Pond	**Pond**	**Emergent Wetland Area**	**Total**
Acres (90% of emergent wetland)	21	11	32
Maintained surface water elevation	1.50	1.50	
Top elevation	7.00	7.00	
Ponding Capacity to 7' NGVD	116	59	175
10% of emergent wetland assumed not to pond (levee area)			
Ponding Capacity of Seasonal Wetland	**Seasonal Wetland**		
Acres (95%)	129		
Bottom Elevation	-1.50		
Invert of Overflow	1.50		
Ponding Capacity to Overflow Invert	388		
Ponding Capacity to 3.5' NGVD (top of assumed 24" culvert)	646		
Possible Maximum (to 7' NGVD)	906		
Delta (per foot>1.5' NGVD)	129		
5% of swale assumed not to pond (levee area)			
TOTALS FOR NON-TIDAL AREAS	**To Overflow Invert**	**To Top of 24" Culverts**	**Possible Maximum**
Swale	471	1168	1690
Expanded Pond	175	175	175
Seasonal Wetland	388	646	906
TOTAL	**1034**	**1989**	**2771**
Subtotal Pond and Wetland	*563*	*821*	1081

HISTORICAL MAPS RELATIVE TO PROJECT AREA

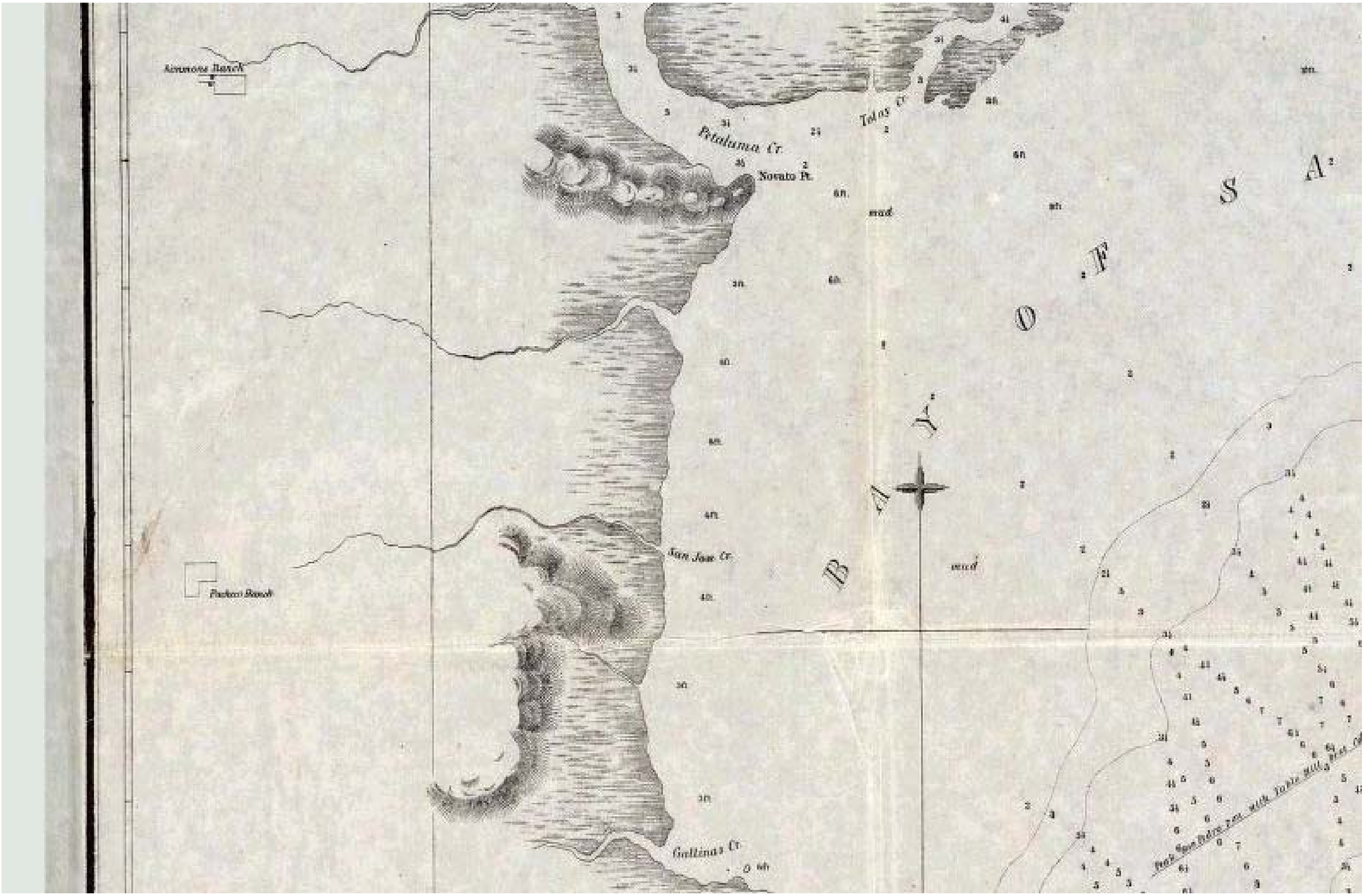
1.	1844	San Pablo Bay	(Eugene Duflot de Mofras)
2.	1852	San Pablo Bay	(Cadwalader Ringgold
3.	1854	San Pablo Bay	(U.S. Coast and Geodetic Survey)
4.	1860	Marin County	(A. Van Dorn)
5.	1874	San Pablo Bay	(Cal. Board of State Harbor Commissioners)
6.	1887	San Pablo Bay	(U.S. Coast and Geodetic Survey)
7.	1897	San Pablo Bay	(U.S. Coast and Geodetic Survey)
8.	1914	Petaluma – 15 min.	(U.S. Geological Survey)
9.	1916	Mare Island – 15 min.	(U.S. Geological Survey)
10.	1942	Petaluma – 15 min.	(U.S. Geological Survey)
11.	1951	Petaluma Point – 7.5 min.	(U.S. Geological Survey)
12.	1954	Novato – 7.5 min.	(U.S. Geological Survey)

PORTION OF 1844 MAP OF SAN PABLO BAY (EUGENE DUFLOT DE MOFRAS)



Ref: Port De San Francisco Dans La Haute Californie. No. 16. (with) Entree Du Port De San Francisco et des mouillages del Sausalito et de la Yerba Buena. Publie Par Arthus Bertrand. Grave par S. Jacobs. Voyage de Mr. Duflot de Mofras. 1844.

PORTION OF 1852 MAP OF SAN PABLO BAY FROM CADWALADER RINGGOLD



Reference: Chart of the Bay of San Pablo Straits Of Carquines and part of the Bay of San Francisco California By Cadwalader Ringgold Commander, U.S. Navy. Assisted by Simon F. Blunt, Lieut. U.S.N. 1850. Projected, Constructed & Drawn by Fred. D. Stuart, Hydrographer, late of the U.S. Ex.Ex. Assisted by A.H. Campbell, Civil Engineer. Entered ... 1851, by Cadwalader Ringgold ... District of Columbia. C.B. Graham, Lithr. Washington, D.C.

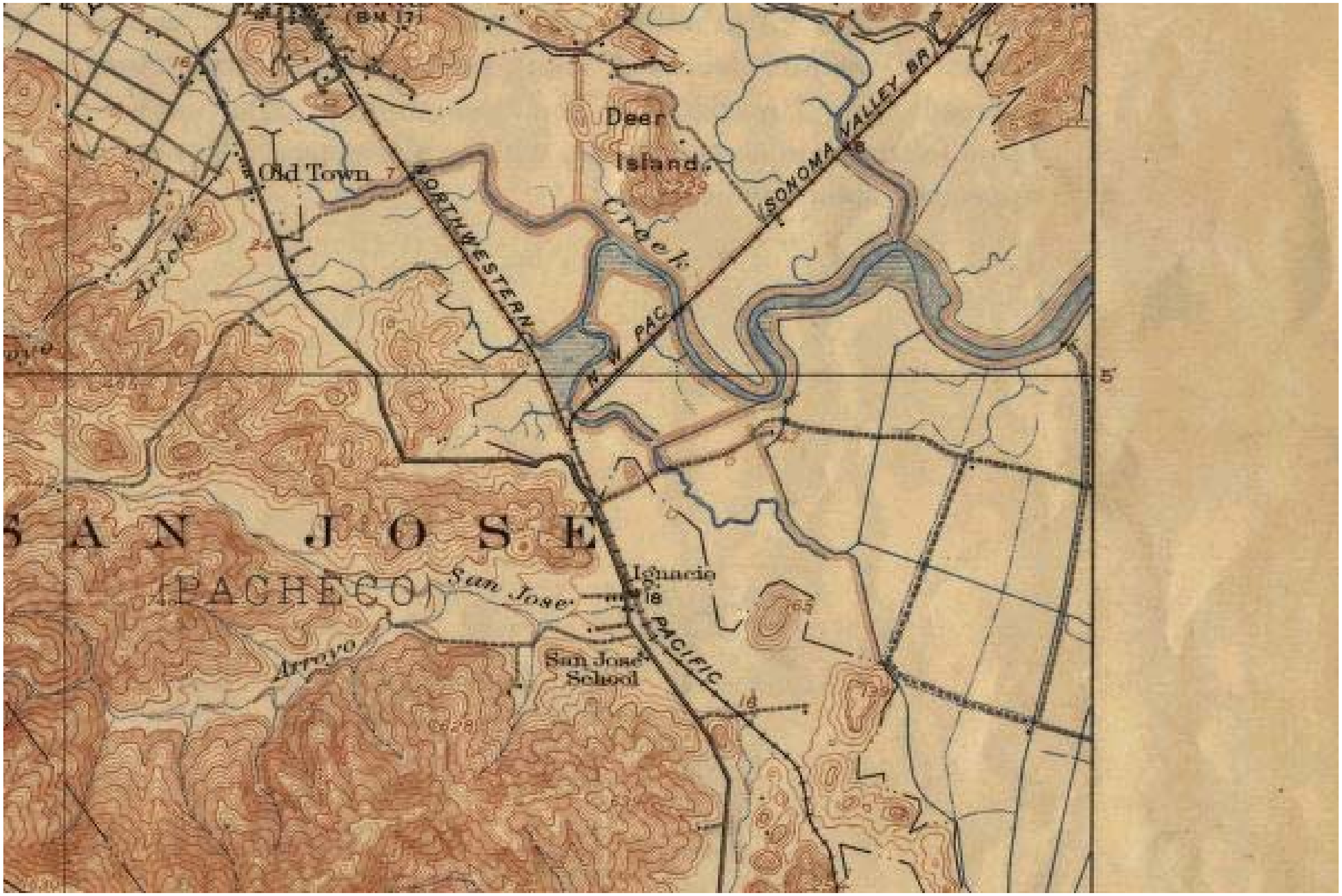
1860 MAP OF MARIN COUNTY

REFERENCE: Van Dorn, A. 1860. Map of Marin County (reviewed at U.C. Berkeley Bancroft Library). Berkeley, CA. Also at: http://library.berkeley.edu/EART/maps/marin.jpg

PORTION OF 1874 CALIFORNIA BOARD OF STATE HARBOR COMMISSIONERS MAP OF SAN PABLO BAY

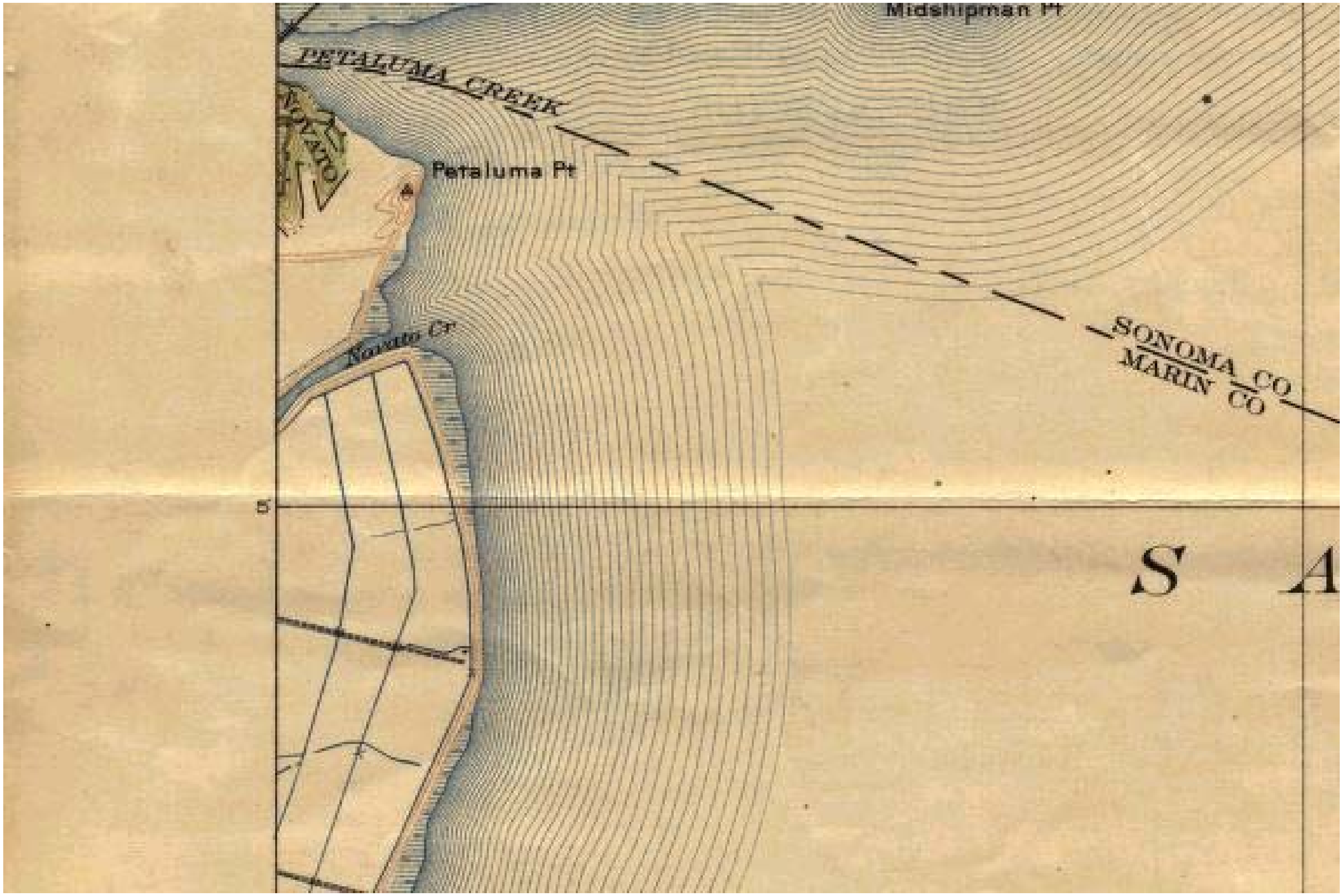
REFERENCE: Map exhibiting the salt marsh, tide and submerged lands disposed of by the State of California in and adjacent to the bays of San Francisco and San Pablo and now subject to reclamation. Prepared from maps of the U.S. Coast Survey & official records by order of the Board of State Harbor Commissioners for the United States Commissioners on San Francisco Harbor. By T.J. Arnold, engineer of the sea wall. 1874. U.S. Commissioners Rear Admiral John Rodgers, Major G.H. Mendell, Prof. George Davidson. State Harbor Commissioners Samuel Soule, T.D. Mathewson, D.C. McRuer. Britton Rey & Co. Lith. S.F.

PORTION OF 1914 U.S.G.S 15-MINUTE TOPOGRAPHIC MAP FOR PETALUMA, CALIFORNIA



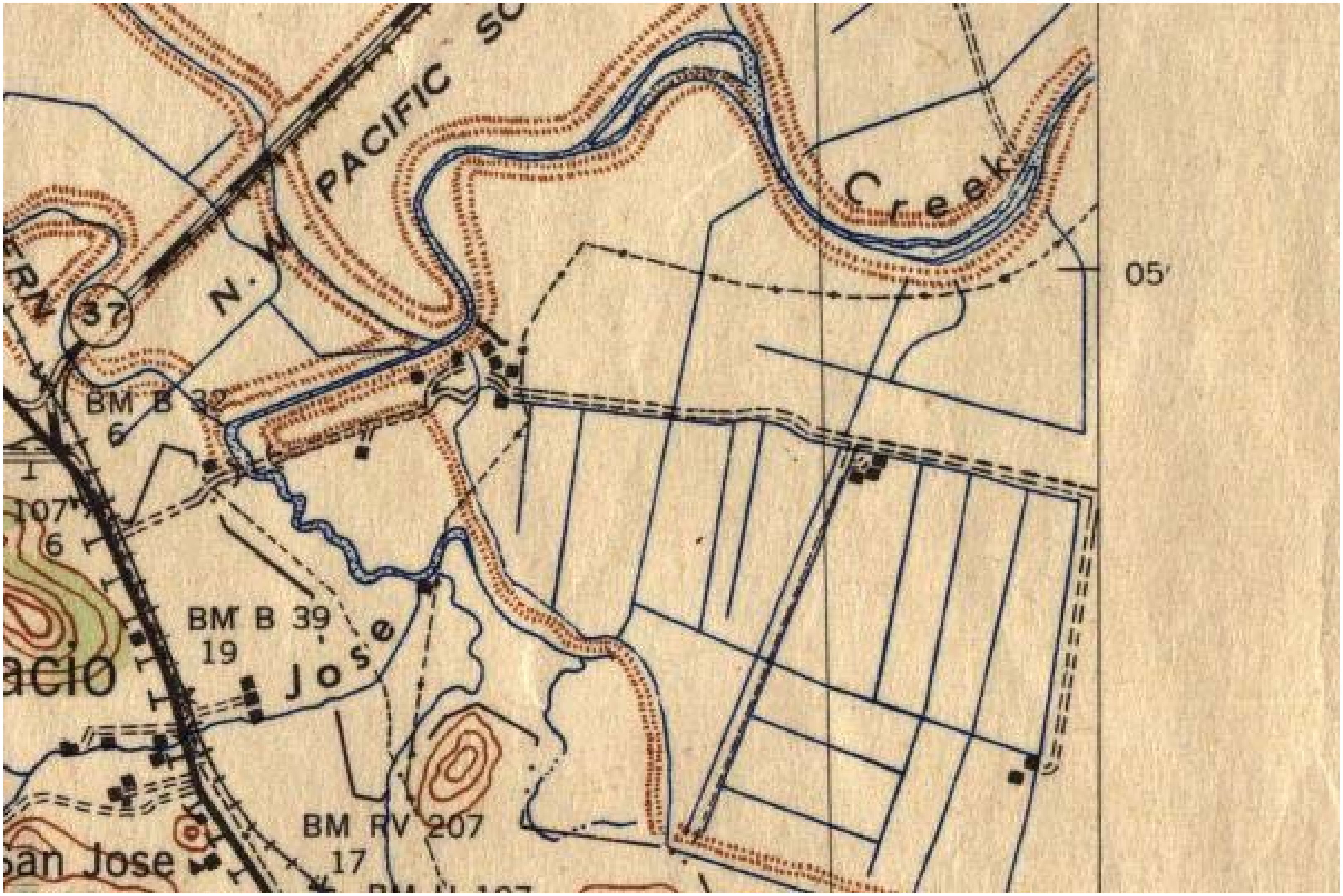
REFERENCE: U.S. Geological Survey. 1914. Reprinted 1924. California: Petaluma Quadrangle. 15-minute Topographic Series. Surveyed 1910-1912. On file, California Division of Mines and Geology Library, Sacramento.

PORTION OF 1916 USGS 15- MINUTE TOPOGRAPHIC MAP FOR MARE ISLAND, CALIFORNIA



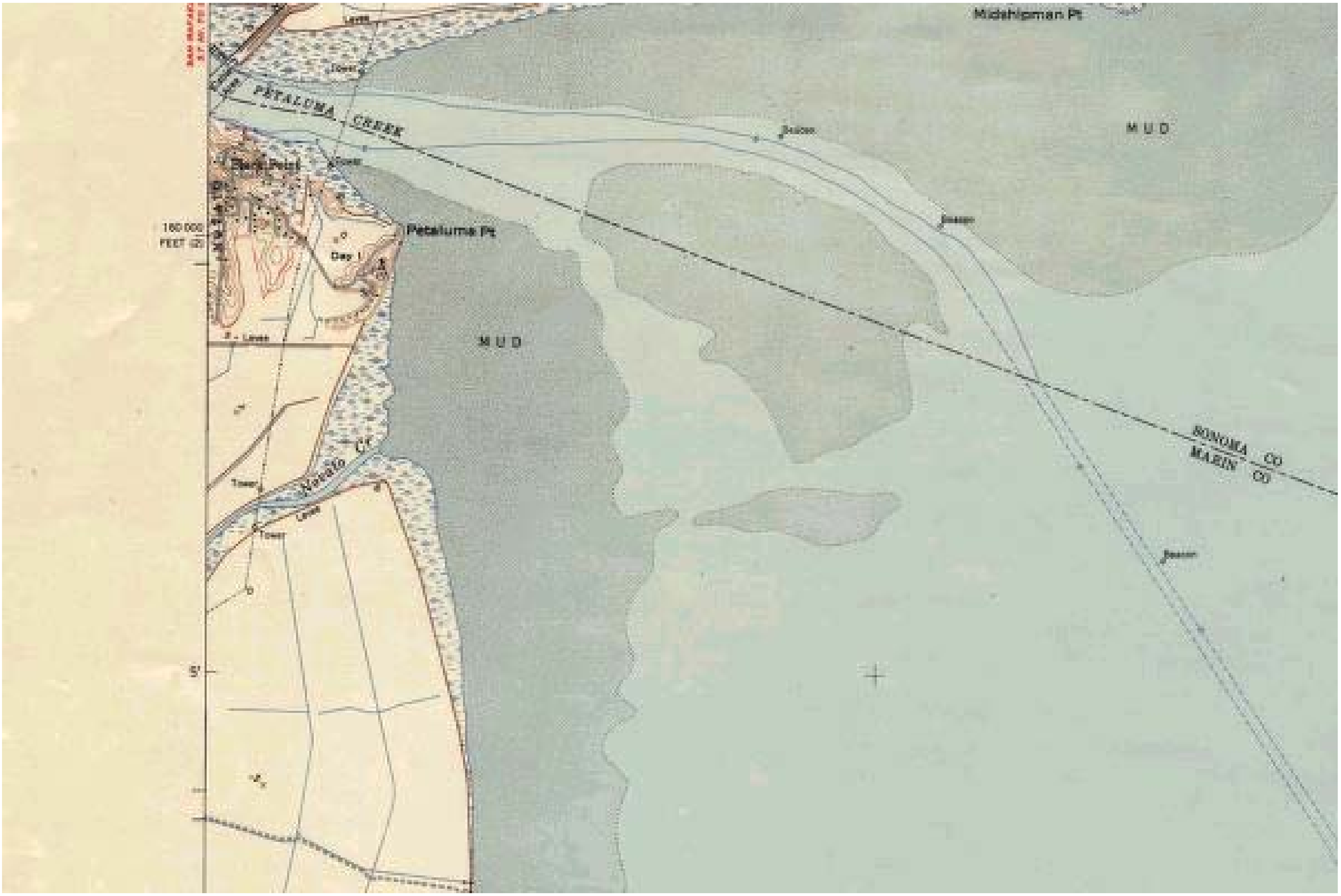
REFERENCE: U.S. Geological Survey 1916. Reprinted 1927. California: Mare Island Quadrangle. 15-minute Topographic Series. Surveyed 1913-1914. On file, California Division of Mines and Geology Library, Sacramento.

PORTION OF 1942 USGS 15-MINUTE TOPOGRAPHIC MAP FOR PETALUMA, CALIFORNIA



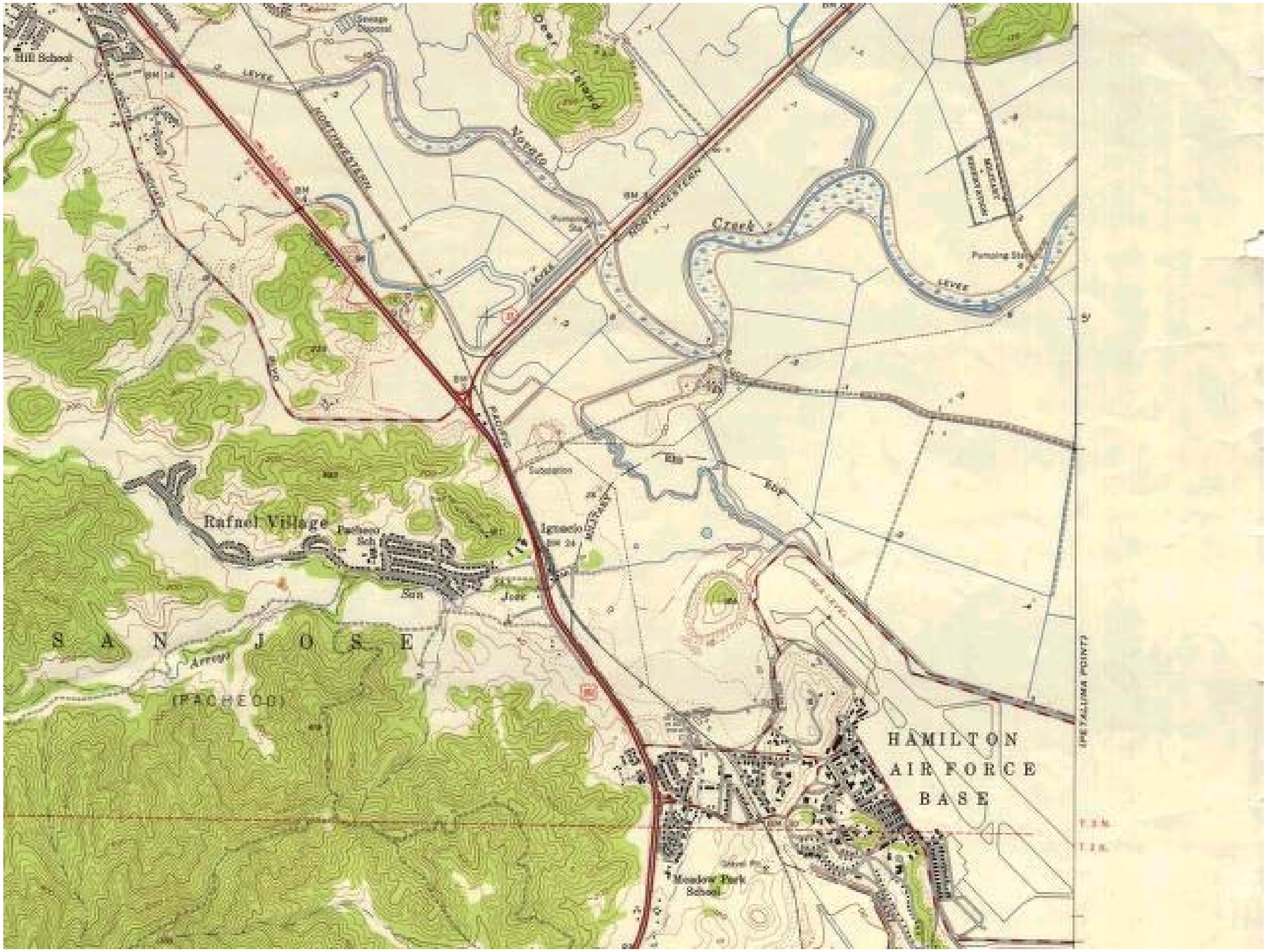
REFERENCE: U.S. Geological Survey. 1942. California: Petaluma. 15-minute Topographic Series. On file, California Division of Mines and Geology Library, Sacramento.

PORTION OF 1951 USGS 7.5-MINUTE TOPOGRAPHIC MAP FOR PETALUMA POINT, CALIFORNIA



REFERENCE: U.S. Geological Survey. 1951. California: Petaluma Point Quadrangle. 7.5-minute Topographic Series. On file, California Division of Mines and Geology Library, Sacramento.

PORTION OF 1954 U.S.G.S 7.5-MINUTE TOPOGRAPHIC MAP FOR NOVATO, CALIFORNIA



REFERENCE: U.S. Geological Survey. 1954. California: Novato Quadrangle. 7.5-minute Topographic Series. On file, California Division of Mines and Geology Library, Sacramento.